TOMORROW'S HOUSES

EDITED BY

JOHN MADGE

M.A., A.R.I.B.A.

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New Building Methods Structures and Materials

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INTRODUCTION

For various reasons, it is harder than ever before to obtain an up-to-date picture of modern developments in building technique. This book has, therefore, been prepared in order to bring together the evidence of experts, and so that the reader may gain a sound picture of what changes are now practicable and of what changes are necessary to the advancement of house design.

Such a book cannot hope to be comprehensive, and it has been thought better to give adequate scope to a dozen contributors than to attempt to cover the whole field in a more sketchy manner. Some omissions are self-evident ; there is, for example, no specific discussion of developments in glass or in plumbing. In spite of this, it is hoped that the book will serve a useful purpose in bringing the hard light of reality to bear on a field which for too long has remained a copywriter's paradise. This is a practical book written by practical men, and there is no place in its pages for extravagant claims.

The war has shown that it takes an emergency to make us realise our capacities. In the war years the magnitude of our need has been equalled only by the scale of our achievements. During this period, despite the complications of wartime life, we have made tremendous strides in reorganising and re-equipping some industries, and in doing so we have been able to boost our output of munitions and of other essential goods to a level above expectation.

This increase in productivity has been accompanied by long working hours and other conditions of work and life which would not be tolerated in peacetime. But that should not blind us to the major contribution to increased output made by the adoption of advanced techniques. For the future we must strive to sustain and increase the rate of technical progress as the one sure means of achieving simultaneous advancement both in conditions of work and in standards of life.

Many peacetime industrial products will be made more simply and more cheaply in the years to come as a result of the improved processes developed in the war. But there are other urgent public needs which have benefited little in this country from wartime experience. House production is an outstanding example, mainly because of the almost complete cessation of domestic building during the war.

The result of the suspension of building is that the testing in practice of new techniques has been limited to the smallest scale ; until comparatively recently, only a nucleus of scientists and technicians could be spared from war work to undertake even the first stages in development. In one

sense there has therefore been a noticeable retardation of technical change in building. On the other hand, the pause has provided an opportunity to return to a consideration of the fundamental requirements of a house, in terms not only of planning and location but also of structure, materials and equipment. In the more recent past there has been an impressive concentration of attention on these problems in official, industrial and independent circles; although this has not yet had the benefit of much practical test, it has laid the foundation for a far more realistic and scientific approach in the future.

For the present, there is no need to stress the urgency of the demand for houses. This will be at a high level for a long time to come, and for at least five years there is likely to be an insatiable demand for every house that can be provided, of whatever type and however constructed. It is clear that the orthodox building industry, relying on well-tried methods, will without augmentation be incapable of supplying the need. The question still to be decided is the form of augmentation to encourage.

It is of very great importance that we should find the correct answer to this question. The scale of operations precludes any idea that the rehousing programme can be treated as a sideline to the main industrial programme of the next decade. During this period, new houses will be the tangible expression of a very large proportion of our capital investment. It is therefore vital that in supplying them we should as far as possible reconcile the various—and often conflicting—considerations which should determine a realistic policy.

The principal requirements can be formulated without difficulty. The first claims are those of the families who are to live in the new houses. From their point of view, the overriding need is for speed in house production.

The householder is also interested in the cost of building. Whether he is in a position to buy or rent his home without state aid or whether he is eligible for subsidy, the cost is ultimately very much his concern. It is true that certain elements which affect the cost to the tenant transcend technical considerations. Prominent among these are the cost of the building sites, the method of price-control and of distribution of materials, and the rate of interest payable on money raised for housing purposes. In spite of these considerations, it is almost inevitable that any unnecessary expenditure on a house or its equipment, caused by inefficient technique, will be passed on to the householder. Expense can be an index of technical backwardness no less than a sign of high quality.

There is another element in cost which can be even more important to the tenant than capital expenditure. One cause for the reluctance of such a large proportion of the public to embark on house-ownership, even when they could afford to do so, is the risk of being saddled with substantial charges for maintenance and repair which any owner has to

accept. It is very often false economy for anyone (except for the speculative builder who gets rid of badly built houses as soon as they are complete) to stint money on first costs. Too often the money originally saved is spent several times over on patching up an unsatisfactory structure or on maintaining uneconomically finished surfaces. On the whole, local authorities have recognised this to the extent of building far more substantial structures than are embodied in the ordinary small house built for sale. And yet there has been very little scientific analysis of the expenditure, particularly on finishings, which is economically justificable and desirable. British practice is unsystematic enough in this respect in all fields, as compared with that adopted, for example, in the United States. Be that as it may, it is not necessary that the useful life of a house and its components should be an unknown quantity in the equation of housing finance. Useful life is one of the performance factors which can only be properly incorporated in the design formula if the qualities of the materials used are controlled.

What else does the individual require of his new house ? There must be, in the present period of stringency, a great temptation to reduce standards of space and of performance (sound insulation for example), on the pretext of getting on with the job of providing a roof over the head of every dishoused family in the country. It is gratifying to see that, except in the case of temporary houses, this temptation has been resisted. Furthermore, official agencies have authorised an improvement in minimum standards over those obtaining at the outbreak of the war, even though these agencies have in some respects watered down the recommendations made to them by expert committees, such as the Burt and Dudley Committees.* There has been a real improvement in purely space standards, but the upgrading is even more emphatic in the case of the provision of equipment. In the absence of encouragement, local authorities before the war tended to equip their council houses to the lowest standard consistent with sanitary decorum. This time the temporary houses have set the pace by incorporating a promising water heating system, together with a refrigerator and adequate storage space, both in the kitchen and elsewhere in the house. It is true that in the first year or so of the rehousing programme the provision of house carcases is likely to outstrip the production of refrigerators and of other equipment, but within a measurable period it will not be difficult to catch up with the demand.

What can be achieved in respect of standards of space and of equipment can also be achieved in respect of ease of running. This is largely a matter of design, and with the amount of thought that has gone into the details of modern design, from windows which can be cleaned from inside the room to coved skirtings to eliminate dust traps, the life of the housewife

* In November, 1945, the new Minister of Health instructed local authorities to adopt the full standard recommended in the Dudley report.

can be made far less arduous. When it comes to surfaces, the resources of modern technology can do much to eliminate time-absorbing finishes and to achieve that degree of labour-saving which is now within our grasp. Furthermore, on the horizon are all the powered mechanical devices which can take the backache out of so many routine household tasks. Here again the principal technical problems are either already solved or else are readily soluble. Mass-production methods could bring them within the reach of every home.

In view of the rapid—and increasing—mobility of the population, it is already the exception for any one family to go on living in the same house for more than a decade. This mobility makes nonsense of the suggestion that security of tenure is the basic element in promoting the stability of family life. Reduction in useful life may remain an extravagance in terms of building effort, but it can hardly be objected to on social grounds. Where new families are to be accommodated, it may in future be the exception—at least during an era of expanding standards—for a family to prefer an old house at second hand to a new one, provided that costs are comparable.

The concept of expanding standards mentioned in the last paragraph is fundamental to any assessment of the future course of housing development. At a time like the present, it is necessary to make a careful distinction between two different forces which are in operation. On the one hand, there is a decisive shortage of housing; this makes it necessary to increase the total number of houses. On the other hand, there is a concensus of opinion that we must replace existing sub-standard housing. As further advances of housing standards are virtually certain, it would be grossly shortsighted to adopt niggardly designs even in the present housing emergency. Unless the new houses incorporate the full measure of the advances which have already been crystallised they will be a bad investment, for they will be obsolescent from the day that they are first occupied.

We can now sum up the requirements of the consumer. These are: houses in a hurry; houses at low initial cost; houses with low maintenance costs; houses not below minimum predictable standards of space and equipment; and finally houses whose main structure can, where desired, survive their original tenants.

It may be felt by the reader that the last few paragraphs lay too much emphasis on the material qualities of a house and too little on those less easily defined characteristics which can transmute a house—"a machine for living in"—into a home. This is an issue which cannot be sidetracked. Various modern surfacing materials still have to win the confidence of the public. It is true, too, that the apparently logical conclusion of the argument about "useful life," however correct on a broad statistical basis, is only valid for acceptance if the history of the individual house conforms as

closely as possible to the history of its inhabitants. It is one thing to assert that social conditions change so rapidly in the modern world that it is useless to plan ahead for more than twenty or twenty-five years. It would be quite another to suggest that the individual will automatically be crying for a change at the end of each period of this length. There is quite clearly no virtue in forcing individuals to change their environment according to the calendar if they are happier to remain where they are, and if they are not impeding the natural development of the community by remaining.

In this issue, the proper course is surely to provide the individual with the opportunity to make his own choice. Certainly if we build hard for the next twenty years, the supply will have caught up with the demand and we shall be in a position to provide a fund of houses sufficiently large to ensure a decent house for every family in the country. From thenceforward it will be the task of those responsible for the housing programme to balance the supply of new houses in a variety of types and sizes with the real demand for them.

The next step is to consider the housing programme in relation to the general scheme of planned economic policy.

In considering the level of prosperity of the country, it is essential to realise that labour and other resources devoted to house building are precluded from providing the other necessities and material amenities of life. If we are justified in assuming that we can achieve a consistently high level of employment, we must also accept the fact that wastefulness in building will automatically depress the standard of living in other directions.

This wastefulness can be of various kinds. The most obvious cause of waste is to provide houses of the wrong kinds in the wrong places. The public interest demands that we should conduct our rehousing according to a planned programme—planned with due regard to what is already available, to the expected changes in the size and structure of the population and to the foreseeable changes in the location of housing demand.

The preparation of a systematic and firmly controlled building programme is probably the only way of avoiding an ultimate slump, which has in the past inevitably followed any large productive boom. Time and time again in the last hundred years we have seen an overconcentration on the provision of one particular commodity ending in oversupply, with a subsequent depression which has spread to all economic activities. There were strong indications that we were heading for a building slump in 1939. This would not have implied that the general level of our housing had been brought up to a satisfactory point, but rather that the types of house being supplied in large numbers in the immediate pre-war years—in particular the speculative suburban villa—were being built in larger quantity than the market justified.

To avert this possibility, it is, therefore, necessary to be able to forecast

the same degree of skill without having to undergo a further term of apprenticeship when he is already an adult.

Another aspect of the problem deserves mention. Although craftsmen constitute the indispensable core of building labour, they by no means make up the whole labour force. In the orthodox building trades, the unskilled workers constitute almost one half of the total, and their role in any reorientation of building technique deserves close consideration. Figures for factory workers are hard to compare, but it is unlikely that more than a quarter of the workers in a normal engineering works are restricted to labourers' rates of pay. The implication of this is clear. In the past the incidence of unemployment and of casual work has been particularly heavy in the case of unskilled building workers. The reduction in the proportion of labourers, such as is brought about by a shift of work from the site to the factory, not only increases the general wage level in the industry but also plays its part in the elimination of unemployment.

The reader who is oppressed by the magnitude of our rehousing task may feel that the preceding paragraphs are unduly complacent, concentrating as they do more on the need to restrict recruitment to some building trades than on stressing the urgency of increasing the total labour force. Such an inference would be totally misleading ; at the moment the site labour force is less than 40 per cent of its pre-war size and the materials supply industry is correspondingly diminished, by factory concentration schemes and by the direction of labour away to war industry. A tremendous drive will be required for the next few years. But this time it is essential that we keep one eye on the future, and plan the immense expansion that is required in such a way as to safeguard the lives of those who take part in the drive. While a rising standard of living will entail a steady increase in the output of engineering products, a housing programme on the scale necessary for the next decade will not be a permanent feature of our national budget, and to plan men's lives as though it were is merely to pile up difficulties for the years to come.

The Building Industry is on the threshold of important technical changes. It is up to us to lubricate these changes. There are many inertias to be overcome, but one sure ally is knowledge. Backed by knowledge, and with the determination and power to carry the job through, this time we have the chance of achieving great things.

SECTION I

ALUMINIUM AND ITS ALLOYS

It may be asked why aluminium has not been used more widely in the past. The main reason is that it is a difficult metal to extract from its ore, and it is only since the large-scale development of electrical power that it has been possible to produce it in commercial quantities. This means that in the present century we have been presented with a range of exciting new materials, light in weight, easily worked, strong, naturally resistant to corrosion and attractive in appearance.

The properties of aluminium and its alloys have made it an indispensable material in war production. This is of course particularly true of its use in aircraft; without the light alloys it would be impossible to produce the majority of modern types. As a corollary, the immense demand has led to extremely rapid expansion of the aluminium industry and to a corresponding mastery of the technique for handling it. Moreover, it appears likely that the cost of production has been permanently lowered to a level at which the light alloys will be able to compete in many fields from which their high price has previously debarred them. Aluminium promises to be one of the few materials in ample supply in the next few years.

In his Paper, Dr. West describes in some detail the properties of aluminium which lead one to expect a rapid expansion of its use in the building trade. Many of these are based on experience, for already it has made its mark in a variety of uses in the home. In text and in illustration, the author is able to demonstrate that aluminium is established as a material well adapted to play its part in supplying the fabric for the homes of today and tomorrow.

ALUMINIUM AND ITS ALLOYS

By E. G. WEST, Ph.D., B.Sc.

INTRODUCTION

It is the desire of all architects to erect a building that will live on, a building that in itself commands a sense of harmony, practicability and peaceful permanence. No wonder centuries old tradition prevails; but to-day there are new materials—metals among them—which in architecture are producing a notable awakening.

In view of the unprecedented volume of building required throughout the world, metals as architectural materials in public and domestic buildings are likely to be used in greater quantities than ever before. In aluminium and its alloys, craftsmen and designers have a medium that has many successful applications in structure, in decoration and for fittings. When they realise with what harmony the aluminium alloys may be combined with the standard materials of the past, and how complementary these alloys are to the new materials, such as plastics and plywood, these creative designers will find unlimited scope in their art, together with ample means at their disposal.

WHY ALUMINIUM ALLOYS?

It is now generally accepted that many materials new to building will in the future be applied on a considerable scale, but before any new material can be accepted it must be shown that its employment is both technically sound and economically practicable. As far as the aluminium alloys are concerned, both past experience and more recent investigations have shown that there are valid technical reasons for their use in a number of applications. To-day there are also definite indications of the post-war price level of this group of materials being substantially eased—already the cost of aluminium in this country has been reduced from the wartime level of £110 per ton to £85 per ton.

In this connection it should be noted that fundamental changes have taken place during the war, of which the most important are:

(i) World capacity for producing aluminium at the end of the war has been estimated as at least six times the 1935 output.

(ii) There will be large stocks of both virgin and secondary metal throughout the world.

(iii) There will be a considerable increase in the amount of plant available for the production and fabrication of the aluminium alloys, together with very large numbers of workmen skilled in the working, joining and finishing of these materials.

It is apparent, therefore, that the cost of finished articles of aluminium alloy will tend to be progressively reduced to the benefit of the consumer. Full account of this trend must be taken in planning the post-war utilisation of the various materials now available for building.

PREFABRICATION

The factory production of units for houses to reduce site work will be adopted to a very considerable extent ; although there is still some disagreement as to how much prefabrication is desirable, it is quite certain that if prefabrication is used as a method of increasing the supply of houses then aluminium is especially suitable for many components on account of the low costs of handling and forming.

The aircraft industry is, of course, the greatest example in this country of the benefits of prefabrication. The high standard of achievement in this field leaves no doubt about the possibility of fabricating aluminium and its alloys for housing purposes. The A.I.R.O.H. house described elsewhere in this book is sufficient evidence of this.

Past attempts in the prefabrication of houses have indicated that commercial success depends on mass production, the cost per house falling as the number made increases. This is fully recognised, and one of the chief problems which must jointly engage the architect and the engineer is how to arrange for maximum flexibility in design whilst keeping to a minimum the number of components, all of which are suitable for simple repetition manufacture on a large scale, and how at the same time to provide dwellings of a pleasing character.

Another very important factor is that erection must be speedy and must require only unskilled or semi-skilled building labour. In this connection, much attention has been given to the possibility of manufacturing large units such as complete walls, roofs and floors in the workshop and erecting them by a small crane. Such units need not be of identical sizes and shapes, and a range of assemblies may be provided from standard basic panels, ribs, etc.

If aluminium alloys are properly used, large units can be handled with comparative ease through all the stages of manufacture, transportation and erection. It should be emphasized that another great advantage in manufacturing large units is that site jointing can be reduced ; jointing is much more efficiently carried out in the workshop where methods may be employed which would be impracticable or uneconomic at site (e.g. spot welding, seam welding, or plastic jointing.)

CHARACTERISTICS OF ALUMINIUM AND ITS ALLOYS IN RELATION TO BUILDING APPLICATIONS

Aluminium and its alloys are clean-looking metals which do not rust, warp or splinter in use. They possess valuable thermal and reflective properties, are easily worked to shape and can be joined by most normal methods. They take an infinite variety of attractive finishes, including plating with other metals, and may be anodised in natural or coloured shades from jet black to delicate pastel tints. The resistance to corrosion of aluminium and its alloys is far superior to that of most other metals, owing to a thin film of oxide which is always present on the surface, making it impervious to ordinary atmospheres. The thickness of this protective oxide layer can be increased by a simple electrolytic process—anodic oxidation—a process which progressively forms and thickens the film from the inside, so that the film becomes part of the parent metal. Thus it cannot flake off and imparts excellent resistance both to corrosive influences and to abrasion.

The most characteristic property of aluminium and its alloys is their low density, which is little more than one third that of the ferrous materials, copper base alloys, zinc alloys, etc.

The range covered by the aluminium-base materials is particularly wide. It is therefore essential that the most suitable alloy should be chosen for a particular purpose; failure to do so leads to disappointment in service. The alloys are available in all the usual forms, namely, sheet and strip, plate and foil, extruded sections, rods and wire, rivets, tubes, forgings, and castings.

The usual structure shapes—angles, channels, I-beams, T-bars—are produced as extrusions and one of the great advantages of aluminium alloys is the ease with which they can be formed by this method in lengths suitable for transportation. Thousands of different sections are available, and tools for specially designed shapes are produced at quite small cost. A range of standard sections is now available in a British Standard No. 1161 (1944). Tubes are made by extrusion followed by cold drawing.

Sheets are supplied in tempers of various hardness. The softer tempers are capable of withstanding a greater degree of shaping than the hard rolled metal.

The working of the metal and its alloys in these different forms is familiar to craftsmen in the industry. There is no difficulty in obtaining accessories such as aluminium alloy bolts, screws and rivets, so there is no limitation placed upon the architect and designer in obtaining supplies of any kind.

THE PROPERTIES OF ALUMINIUM ALLOYS

Although the oldest of the aluminium-base alloys have been available for over thirty years, recent development has been very rapid and the engineering requirements which the materials can fulfil to-day are particularly wide.

Pure aluminium is available in several commercial grades, varying from 98 to 99·99 per cent purity, the chief impurities being iron and silicon. In its wrought condition the mechanical strength of the pure metal is low, the ultimate tensile strength ranging from 5 to about 9 tons per sq. in., according to the amount of cold working it has undergone. The wrought aluminium alloys, on the other hand, include materials which have strength values of 25–35 tons per sq. in. and even higher.

The aluminium alloys are usually divided into two principal classes: the casting alloys and the wrought materials.

The first process in the production of all aluminium alloy articles is that of casting. The casting alloys are used for components on which no further working operations, other than machining, are required, while the wrought alloys are first cast in cylindrical or rectangular billets of dimensions suitable for subsequent working. Suitable casting alloys are available for many building components made hitherto of other metals or of non-metallic materials. Expert advice should be taken in the choice of both alloys and methods of manufacture, in order to achieve maximum efficiency.

Wrought materials are produced by the mechanical working of cast ingots or billets, as a result of which the homogeneity and properties show a considerable improvement over those of cast metal. Working may include extrusion, hot and cold rolling into sheet and strip, forging by hammer or press, and drawing into tubes and wire. Cold working of aluminium and its alloys increases their tensile strength and at the same time reduces ductility. The mechanical properties of work-hardened alloys thus depend on the degree of working, and many alloys can be obtained in various tempers such as hard or medium hard.

The alloys are also subdivided into two main groups—those in which mechanical strength is developed entirely as the result of working, and those in which it is developed by a final heat-treatment.

The strengthening of certain aluminium alloys by heat-treatment was discovered about 1907, in an alloy similar to "Duralumin." When this alloy was quenched from about 500°C. it became soft, but after standing for several days its strength increased to a level considerably above the original figure. This was the first time that age-hardening had been noticed. To-day there are other age-hardening alloys, including some which require low temperature precipitation to produce maximum properties. The behaviour of the aluminium alloys is different from that of steel, which is at its maximum hardness immediately after quenching.

The heat-treatable alloys may be further separated into two divisions: those given a single heat-treatment followed by natural aging, and those which require a double heat-treatment for the development of maximum strength.

Physical Properties

The physical properties of the aluminium-base alloys vary according to the composition and condition of the material, and the limits of composition of current specifications are generally too wide to allow exact figures to be given. Precise information can be obtained, however, from the manufacturer of particular alloys.

The outstanding property of aluminium and its alloys is, of course, their low density, which ranges from 2·63 to 2·82, compared with 7·8 for steel, 8·9 for copper, 7·1 for zinc and 11·3 for lead. A cu. ft. of aluminium alloy weighs approximately 172 lb. as against 486 lb. for steel, about 112 lb. for brickwork and about 140 lb. for concrete.

The thermal properties of aluminium and its alloys also differ from those of other common metals. The melting point of the pure metal is 660°C. and the melting range of the alloys is from about 520°C. to 650°C. according to composition.

The coefficient of expansion is about twice that of mild steel.

The Specific Heat (20–100°C.) averages 0·24 cal./gm., or 0·432 B.Th.U./lb.

The Latent Heat of Fusion is approximately 92·4 cals./gm., or 166·3 B.Th.U./lb.

Values for coefficient of linear expansion and thermal conductivity are given in Table 1, together with electrical resistivity figures.

TABLE 1.

Thermal and Electrical Properties of Representative alloys

Material*	Melting Range	Coefficient of Linear Expansion per °C.	Thermal Conductivity at °C.		Electrical Resistivity. Microhms/c.c.
			C.G.S. Units	Compared with Copper	
Commercial aluminium.	659°C.	$24{\cdot}0 \times 10^{-6}$	0·50	51%	2·845 (B.S.S.215)
D.T.D. 182A	530–620°C.	$27{\cdot}6 \times 10^{-6}$	0·2	20%	6·4
B.S. L46	570–640°C.	$24{\cdot}0 \times 10^{-6}$	0·3–0·39	32–42·5%	4·0–4·9
B.S. 4L25	530–640°C.	$22{\cdot}5 \times 10^{-6}$	0·33–0·42	35–44%	3·7–5·05
B.S. 5L3	530–610°C.	$22{\cdot}6 \times 10^{-6}$	0·3–0·45	37–47·7%	3·3–5·3

* Typical alloys indicated by Specification Numbers.

MECHANICAL PROPERTIES

The mechanical constants for all the aluminium-base alloys are approximately as follows :

Young's modulus of elasticity	10×10^6 lb./sq. in.
Torsion modulus	$3{\cdot}8 \times 10^6$ lb./sq. in.
Poisson's ratio	0·32

The modulus of elasticity is seen to be about one-third that of mild steel, i.e. for a specific stress the elastic deformation is approximately three times that of steel. Hence, for applications in which resistance to deformation (stiffness) is the chief factor, allowance for the difference in elastic modulus must be made by a change in the geometric form of the section, i.e. by increasing its moment of inertia. The lower elastic modulus also tends to cushion impact shocks—an important practical advantage.

A summary of the usual mechanical properties of representative aluminium alloys is given in Table II.

TABLE II

MECHANICAL PROPERTIES OF REPRESENTATIVE ALUMINIUM ALLOYS

Alloy-type* Specification	0·1% Proof Stress (tons/sq. in.)	Ultimate Tensile (tons/sq. in.)	Elongation on 2 in. (%)	Brinell Hardness No.	Shear Stress (tons/sq. in.)	Endurance Limit 100 × 10⁶ cycles	Endurance Limit 500 × 10⁶ cycles
Commercial aluminium .	2–9	5–9	35–5	18–45	4–6	—	2·2
B.S.L46, L44 .	5–17	11–16	16–4	40–65	7–10	—	—
D.T.D.182A, 297	8	20–23	20	70–80	16	—	—
D.T.D.423A .	17–23	22–26	8	100–120	12	—	—
B.S. 5L3, 6L1 .	14–17	25–32	20	100–120	15–16	—	6·7
D.T.D. 364A .	24–26	28–30	8	130–155	18–20	—	—
D.T.D. 363A .	28–33	33–38	8	130–140	17	—	—

RESISTANCE TO CORROSION

Aluminium and its alloys do not rust or corrode in any way like ordinary steel and practical examples of their high resistance to corrosion are given later. Their resistance varies somewhat according to the composition of the alloy, those containing copper being rather poorer in this respect than those which are copper-free. Particular note should be made of the aluminium-

*The Specification numbers given in this column indicate the type of alloy ; the figures in the other columns are based on these specifications but contain supplementary information.

magnesium series, containing from 2 to 7 per cent magnesium, as they are especially resistant to marine atmospheres and are not heat-treatable.

Much of the success to be achieved in corrosive environments therefore depends on the selection of the most suitable alloy for the required purpose, and advice should be sought when specific applications are being considered.

Aluminium alloys will give the best service when they are kept clean and free from dirt deposits. Under more severe conditions good protection is afforded by painting or stove enamelling, and by a suitable combination of primer and decorative coats permanent and attractive finishes may be obtained.

Another important point to be mentioned is the effect of electrolytic corrosion, which occurs when any two metals are in contact, one of them being preferentially attacked. Figures for electrolytic potentials are given in Table III. The degree of corrosion when aluminium alloys are in contact with zinc, cadmium and steel (especially stainless steel) is very small but increases when the second metal is copper or nickel.

TABLE III

*Electrolytic Potentials of Various Metals against Pure Aluminium

Metal.	Potential (mv.).	Metal.	Potential (mv.).
Magnesium	−850	Tin	+300
Zinc	−350	Brass (50% zinc)	+500
Cadmium	−20–0	Nickel	+500
Pure aluminium . . .	+0	Brass (30% zinc)	+500
		Copper	+550
Alloys to B.S. L46	+100	Silver	+700
D.T.D. 182A. . . .			
Alloys to B.S. 5L3, 6L1 .	+150	Mercury	+750
Iron—mild steel . . .	+50–150		
Lead	+250	Gold	+950

The values given in Table III are the stationary potentials against pure aluminium in 3 per cent sodium chloride solution without aeration, at 18–20° C.

From these figures it will be realised that the aluminium alloys are highly electronegative towards most other metals, so that they will corrode if placed in contact with, for example, copper or copper alloys. To prevent such corrosion, the aluminium alloys should as far as possible be insulated from other metals by asphaltum, bituminous paint or even better by zinc chromate primer. Fibre washers are used between dissimilar metals, fitted where possible under the heads of screws, bolts, etc. Cadmium-

*Based on Table III, Electrode Potentials of Metals, Turnbull and Davis, Ministry of Aircraft Production, R. and M. No. 1901 (6,204), A.R.C., Technical Report, H.M.S.O., 1942.

plated or galvanised nuts and bolts are often employed in positions where parts have to be repeatedly assembled and taken apart.

With all metals, corrosion is intensified in the presence of moisture or entrapped water. Precautions similar to those taken with other metals should not be neglected with aluminium alloys.

Maximum resistance to corrosion, combined with highest mechanical strength is obtained by cladding a high strength heat-treatable alloy with pure aluminium ("Alclad"); this form is used extensively in aircraft.

The resistance to attack can also be greatly improved by anodic oxidation, by which the natural film of impervious oxide is increased in thickness from a few molecules to as much as 0·001 inch.

COLD FORMING

The pure metal and the wrought non-heat-treatable alloys generally possess good cold-working properties, but severe cold forming may necessitate a series of operations with intermediate annealing. The heat-treatable alloys require greater care, particularly in pressing and deep drawing, and working is carried out either on fully softened (annealed) material or on solution-treated material within a short time of quenching or of removal from refrigerated storage chambers.

The forming of sections from strip has been extensively developed in connection with the aircraft industry, and the production of complex sections is possible. Formed strip sections, tubes and extrusions may be manipulated to the desired form.

Many methods of forming and new types of equipment have been developed for cold working aluminium and its alloys in the factory. Such processes include the rubber die press and stretching press for sheet metal components, as well as the pneumatic drop-stamp. All these allow high production rates with little skilled labour.

JOINING

Riveting has long been used as the standard method of joining aluminium sections, and automatic riveting machines maintain a high rate of production on straightforward assemblies. The rivets used may be of pure aluminium, of heat-treated duralumin-type material or of alloys containing magnesium as the principal addition element. They may be solid or tubular and, for liquid-tight joints, sealing compounds are employed.

Jointing of light alloys with plastics as adhesives is now receiving considerable attention, but at present knowledge of the mechanical behaviour of these joints is limited.

While *soldering* is possible by the use of special fluxes and solders combined with a suitable technique, it is not recommended, owing to the very low resistance to corrosion of the joint. Aluminium brazing, however,

is being increasingly used, particularly the furnace brazing process for mass-produced assemblies. The usual brazing metal is an alloy of high silicon content, and the application is limited for most purposes to the non-heat-treatable alloys.

Aluminium itself is readily *gas welded*, provided the technique used takes into account the special properties of the metal, and detailed information on welding procedure is available. The non-heat-treatable alloys are weldable, but modifications in technique are necessary, for example, increased magnesium contents necessitate different flux mixtures to remove the oxide, and a high rate of welding is essential. Site welding of aluminium has been carried out on buildings. Castings are readily welded by gas or arc processes.

The heat-treatable aluminium-base alloys can be fusion-welded, but optimum properties are not obtainable on welded components, even if it is practicable to reheat-treat the completed assembly. There is also the risk of cracking in and alongside the joint during welding.

The metallic arc process is used only to a small extent for pure aluminium and the non-heat-treatable alloys, but developments in this field are expected. The carbon arc has been used to a limited extent.

Spot welding is applied very successfully to the high-strength alloys, but owing to their high electrical conductivity, all the wrought aluminium alloys require current densities considerably higher than those used for steels, and the welding must, therefore, be done in the factory. The degree of control of current, pressure and time is of extreme importance, and automatically controlled machines are available for spot welding sheets up to approximately 0·13 in. thick. Sheet can also be welded to extruded sections or several sheets can be welded together.

Seam welding has been used to a limited extent, but flash and butt welding methods are not yet employed on a large scale.

SURFACE FINISHING

There are many commercial methods of finishing the aluminium alloys—polishing and similar mechanical processes, pickling or chemical etching (frosting, etc.), electro-plating, anodising, painting, enamelling, etc.

Anodic oxidation is the most important surface-treating process for the aluminium alloys, and is used either " as formed " or after " sealing," with or without colouring, or as a base for paints. Anodising is an electrolytic process, rather simpler than ordinary electro-plating, by which the natural film of aluminium oxide is considerably thickened to give a hard coating with very high resistance to corrosion. Films of considerable flexibility can also be produced for special purposes, and in all cases the film is very adherent and will not flake off.

There are two main processes, the one using chromic acid as an electrolyte (the original Bengough-Stuart process), the other using sulphuric acid. Oxide films exceeding 0·001 in. in thickness can be obtained by the selection and control of suitable processes.

The film possesses the property of reacting with and absorbing certain dyes and pigments to give a wide range of coloured finishes. The undyed film, which may be varied from dull grey to silver, is extensively used for outdoor applications. If colour finishes are to be used outside, it should first be ascertained whether they are fast to sunlight.

As an alternative to anodic oxidation, it is possible slightly to thicken the oxide film by an alkaline chromate treatment, which is also a rapid and inexpensive means of preparing the surface for painting, enamelling or lacquering. The M.B.V. (Modified Bauer-Vogel) process is typical of such processes.

Paint can be applied direct to dry, clean aluminium alloy surfaces, although it is better when preceded by a chemical process or acid dip. Some of the usual paint pigments are not suitable, owing to the possibility of reaction between heavy metal oxides and the aluminium, but zinc oxide and zinc chromate are both satisfactory, the latter having a valuable corrosion-inhibiting effect.

THE APPLICATION OF ALUMINIUM ALLOYS IN BUILDING

The following represents a summary of building applications which are typical and the list is by no means complete.

As other countries, especially U.S.A., France and Germany, were far ahead of this country before the war in the application of aluminium alloys to building, it is possible to note some interesting foreign examples and to profit from their experience.

Glazing Bars and Windows

Aluminium alloy glazing bars were in use over 14 years ago and found increasing application up to the outbreak of war when they competed successfully with bars of other metals. The effect of weathering on many of these installations has recently been investigated and in all cases the findings have been very satisfactory.

A good example is given by the aluminium alloy glazing bars used in the Dudley Zoo Bird House, a circular building some 40 ft. in diameter lit from above by means of a complete circle of roof glazing. It was found that the only effect after six years of exposure to the weather outside and the internal atmosphere peculiar to such a place was that externally the bars had acquired a dull grey colour; otherwise they were in perfect condition. Internally the bottom surfaces of all bars were covered with a

fine scaly film but by rubbing with a damp cloth a bright surface could be obtained.

Although six years cannot be regarded as a satisfactory test period for roofing materials, the exposure for this period of a material *in its unprotected condition* must be regarded as highly encouraging.

Another report following the examination of aluminium alloy glazing bars in lantern lights at Hammersmith L.C.C. Hospital shows that although the bars have received no protective coating and have been in position for nine years they are in excellent condition. A slight coating of soot covered the bars, but although conditions are urban with a moderate degree of industrial pollution from heavily built up surrounding zones and a railway in the vicinity, neither uniform surface corrosion nor pitting was visible. It is concluded that such bars may be exposed for many years in polluted urban atmospheres without any form of protection and yet remain practically free from attack.

The conclusions drawn from a further investigation of glazing bars in a lantern light installed 12 years ago is that aluminium alloy bars may be exposed for many years without protection and without more than slight superficial attack occurring.

Apart from the superior appearance of aluminium alloy bars their weight is much less than those of other materials, so that it is possible to reduce sections of the supporting structure.

A very fine example of the use of aluminium in connection with glazing is the Conservatory in the Botanical Gardens, Washington, U.S.A. where the alloys have been used to a considerable extent for the main structure in addition to glazing bars.

The fact that by the extrusion process shapes much too complicated for rolling may be obtained is a great asset to the design of suitable glazing bars.

For some years prior to the war, aluminium alloys were used for windows in high-class buildings and investigations of these recently conducted have encouraged the extension of application to all types.

If it is considered that the alloy window frames should have some further protection than that afforded by the protective film which forms on exposure, anodizing or chemical oxidation may be specified or the metal may be painted.

The maintenance of aluminium alloy windows is low even where a very damp or polluted atmosphere is present, as in the case in kitchens and bathrooms. This is partly due to the fact that corrosion does not take place below the paint film as does rust on steel windows.

If the frame is wiped over when the window panes are cleaned no anodizing or painting is necessary ; if the atmosphere is rural, protection of any kind is again considered unnecessary ; for very polluted atmospheres protection by anodising or painting may be considered advisable ; for

conditions between the last two mentioned no protection may be necessary but the precaution may be considered desirable. Sea air conditions are dangerous to most metals, but the aluminium-magnesium alloys, containing 3 to 5 per cent magnesium and free from heavy metals, are highly resistant to marine corrosion and alloys of this type may be successfully used for aluminium alloy frames.

Sliding windows and sashes in which lightness is very desirable call for the application of aluminium alloys ; this type of window appears to be increasingly popular and easier manipulation ensures still wider adoption. Investigations are now proceeding on the problems involved in manufacturing light alloy windows on a large scale, both by casting complete with fittings and as butt welded assemblies.

Extruded aluminium alloy sections have been exclusively used heretofore, the corners of the frame being fusion welded, and it appears that such construction will continue in the immediate future. Much experimental work has also been carried out for the manufacture of pressed aluminium alloy and cast aluminium alloy frames and it appears probable that they will offer competition, especially in connection with the smaller windows.

Doors, Door Frames and Partitions

Aluminium has been used for a number of years in the construction of doors, generally as a decorative feature on a wood frame. Shop doors with large glass areas have been made in numbers to meet an ever increasing demand, owing to the excellent impression they create. Further, they may be as much as 20 per cent lighter than a door of the same dimensions in wood. It is possible that the experience gained in the fabrication of aluminium alloy sheet and extruded sections in the aircraft industry can be used advantageously for assembly of ordinary domestic doors.

The simplest form of construction is a pressed sheet door, having a beaded edge turned over on all edges and a stiffening member spot welded on the surface ; other, more satisfactory, forms are also possible. Thus a composite door may be built up of light extruded sections faced on both sides with aluminium-faced plywood and filled with a cheap insulating material. Panels, beading or similar decorative features can be simulated during pressing operations if required and locks, hinges, finger plates and other furniture may form an integral part of the door. Composite doors of aluminium alloy sheet facings on a plastic medium, fibre board or similar materials are very suitable for most purposes. Door frames and linings may be produced to suit different types of construction and for particular site conditions. A simple form is an extruded section, without architrave, the frame mitred and welded ; the same result may be obtained by light gauge aluminium sheet drawn over a wood core. The combinations described above set a standard of precision door fitting hitherto

unknown. Aluminium alloy doors have the advantage of being light, draughtless, with good heat insulating properties, and above all, are free from warping, while interior doors require no paint. The surface should be protected by anodising, and if further distinction is required the metal may be dyed to conform with a particular colour scheme.

So far, interior doors have been discussed, but for exterior purposes aluminium alloys may be used for their distinctive appearance and qualities alone, especially for front entrances, while for doors facing south the reflective properties of aluminium not only help to equalise room temperature but completely eliminate the troubles due to paint blistering and panel cracking.

Perhaps the greatest of all advantages in using aluminium alloys is found in the case of the larger sliding and folding doors or partitions used for dividing rooms. Here the saving of weight is of prime importance, as has been proved in its uses for revolving doors.

The distinction between doors and partitions is somewhat indefinable, especially as the functions of partitions and doors are frequently combined. Doors may range in size up to those which are fitted to airship hangars and with their increase in size the difficulty of opening and closing increases. It is readily recognised therefore that aluminium alloys are well suited for the large type of door, for only about one-third of the effort is required to operate such doors as compared with steel doors.

In the case of sliding doors the reduction in weight enables the section of the supporting structure from which they hang to be proportionally reduced in size.

Again, when doors are hinged their self weight creates a bending moment on the posts to which they hang ; as these must be provided with foundations sufficient to accommodate the overturning moments there is again an evident advantage in reducing this moment. In cases where a considerable span is required, as for a level crossing gate, the forces in the bars of the gate itself are reduced by using aluminium alloys.

It is thus seen that the advantage of the lighter material is cumulative ; it may well be that doors and partitions may be constructed of aluminium alloys up to a size which would be prohibitive in steel.

The corrosion-resisting properties of aluminium alloy are also of great advantage where maintenance is difficult. Low maintenance is, of course, especially desirable in house property of all types.

Metal Trim

Increased uses are being found for aluminium formed strip or extruded sections for all purposes where metal trim is applicable. It may be supplied direct from the factory in stock lengths or made up ready for fixing. Items coming under this heading include door-linings, linings for interior win-

dow reveals and external cills, architraves, skirtings, picture rails, fillets, expansion strips, fixing beads, etc. for both prefabricated buildings and those constructed by conventional methods.

The ease of fabrication and the variety of the forms of aluminium and of aluminium alloys make them particularly suitable for this type of work. Skirtings and picture rails are usually made from formed strip which, if anodised in one of the silver-grey finishes, harmonises with the decoration of most rooms, or if more striking effect is desired aluminium alloys may readily be produced in a wide range of brilliant colours or delicate pastel shades.

As the anodised surface is particularly good as a base for paint a colour scheme can be redesigned with the knowledge that high quality finish can be imparted to aluminium trim—a finish that will outlast the rest of the decorations owing to the non-corrosion properties of the metal.

Lifts and Escalators

Lifts made largely of aluminium have been installed in Paris, Chicago and New York. It has been possible in this way to reduce the weight of the lifts by up to 50 per cent. Smaller counterweights are required ; less power is necessary ; acceleration and deceleration can be more easily effected. It may be added that collapsible lift gates in aluminium alloys are remarkably easy in operation.

In this country, a lift using a high percentage of aluminium alloys may be seen at Unilever House, London, whilst another British example is that of the lifts in the liner Queen Mary.

The lift cages may be framed in aluminium alloys and panelled or designed as a stressed skin unit without framing. The lift shafts in the famous old liner *Mauretania* provided an excellent example of the long life of aluminium for such purposes.

Escalators wholly of aluminium alloys have been built in this country for Messrs. Simpsons of Toronto and a good example of facings and mouldings may be seen in the escalator at Messrs. Harrods of Kensington. There appears to be no reason why escalator treads and risers should not be made of aluminium alloys instead of wood, for here lightness is desirable and the length of service would be considerably increased.

Structural Facing and Cladding

A use of aluminium already followed in this country, and even commoner in the U.S.A., is for wall-facing or cladding in the form of spandrel, pier casing and panel. The chief advantage is the great reduction in deadweight of walls. This is an important consideration in multi-storey buildings.

Spandrels are often cast, the technique affording good opportunity for

intricate detail at little extra cost, though solidly backed sheet can be used equally well and is lighter in weight. Pier casings are mostly extruded; where one section may not be sufficiently wide the whole can be built up from a number of extrusions. Panels are generally of a thin gauge sheet solidly backed (fibreboard, plywood, etc.) and fixed to framed walls and partitions. Solid backing is necessary to obtain rigidity and freedom from an appearance of wavyness, which is particularly noticeable when a high specular finish has been specified.

Light Reflectors and Fittings

Pure aluminium has a reflectivity of about 60–70 per cent incident light and visible radiation, but as a result of special electrolytic treatment,—"Brytal" and "Alzak" processes—the efficiency of reflectivity is increased to about 80–85 per cent for the specular finish and 75–80 per cent for the diffuse finish. The latter materials used as reflectors, when properly maintained, retain their high efficiency under severe conditions of temperature and exposure; the hard gloss-like coating permits cleaning to be done merely by wiping with a damp cloth. The use of these processes has been restricted by war conditions to service applications, but has a considerable future for factory and street lighting.

Anodised aluminium is also expected to have extensive uses in electric light fittings, owing to the ease in which the metal can be formed and also to the infinite design possibilities when coloured metal is used in conjunction with other modern materials. An important characteristic of the anodic film is its insulating property. On a good sealed sulphuric film, break-down varies on weak spots to between 150 and 250 volts, while on good points it may be as high as 500–600 volts. The insulation properties do not break down under heat.

Roofs

Roofs have been designed in which aluminium alloys were used for the structure or the weather-resistant covering or for both. Several schemes of this kind may be mentioned. In one, light frames at 2 ft. 6 in. centres, with members extruded to the required sections and roof panels composed of aluminium alloy joined by an adhesive to insulating material, were used, the frames being prepared to accommodate ceiling panels. In another, beams at similar centres, adapted to flat roof construction with ceiling slung below, were employed. A central longitudinal lattice girder supporting ribs about 2 ft. 6 in. centres, with roof panels and suspended ceiling as above, was a feature of a third design. In a fourth, use was made of two longitudinal girders which formed a flat between their top booms—

and a pitched roof from top booms—to eaves, the covering being of aluminium alloy troughing on which rested insulation boards with weather-resistant aluminium-faced surfaces. These represent only a few of the ideas which have been studied and in which the advantages of lightness, heat insulation, finish and corrosion resistance have been exploited. The question of the transport by a light crane of the roof fully fabricated and ready for lifting in sections as large as transport facilities permit, or in panels and pieces, has received a great deal of thought.

These roof systems are considered primarily in conjunction with brick walls, but they may be incorporated in wholly prefabricated buildings. It appears preferable in the latter case, however, to work out special designs where roof and walls may be considered in combination.

Flat roof construction seems to be distinctly attractive to many architects on both aesthetic and economic grounds. Troughing of aluminium alloys may be used to provide the rigidity, but there are many other structural forms possible, e.g., box sections. Weathering may be of suitable aluminium alloy which may be gas-welded; insulation may be considered sufficient if a hardboard ceiling is used for the underside but, if desired, further insulation may be added by insulation boards between weathering skin and troughing, or by aluminium alloy foil inside the boxes. A composite slab consisting of aluminium alloy filled with an inexpensive insulator such as sawdust or sawdust concrete may find use both in this case or in the construction of floors.

Aluminium alloy sheets may be obtained pressed or corrugated to any pattern and possess great ductility so that they can be bent and shaped; this ensures a wide scope to the designer. Joints may be welted when employing flat sheets but less expensive methods are possible, such as lapping the ends and sides, turning the sides up and providing special cover junction strips, or turning the sides down into a channel formed in the aluminium alloy extruded support and filling up the channel with a bituminous material. The use of plastics for jointing is being explored.

The extrusion of special aluminium alloy jointing sections should be noted; these may have thin outstanding arms which may easily be bent down over the bent-up edge of sheeting so that a sound joint is provided.

Gutters and Spouting

Rainwater goods are preferably of aluminium alloy where this material is used for the roof. Aluminium gutters and down-pipes may be manufactured in the same manner as steel gutters, but greater lengths may be employed. Red lead must not be used in the jointing as corrosion may be accelerated; one of the plastics non-injurious to aluminium should be used.

INSULATION

The increasing use of panel walls in place of load-bearing brick walls has focussed attention on the need to take special precautions against excessive heat transmission. Aluminium alloys can play an important part in bringing thermal conductivity down to a satisfactory level.

Although the heat conductivity of aluminium alloys is approximately twice that of steel its value as an insulator is notably high on account of the high percentage of radiant heat which is reflected. The reflectivity of the alloys " as produced " may be up to 40 per cent that of front-silvered glass; by the special electrolytic treatment mentioned earlier it may be increased to over 80 per cent. After some years, weathering reduces the reflection value from 60 per cent to probably 30 per cent if used externally, but the inner surface retains almost its original state, as does interior panelling.

Insulation by means of a material of low-conductivity is widely appreciated, but the control of radiant heat has been given less attention. Some idea of the importance of the latter may be noted from the heating of rooms by open fires. The heat rays are projected to the surrounding walls, furniture and air. Air is a poor conductor but carries heat by circulation; of the heat projected by the fire the greater portion reaches the surrounding walls as radiant heat.

The absorption of these rays varies from 100 per cent in the case of a completely black surface to nil for a perfect reflector, and the percentages quoted for aluminium alloys are relative to these.

Again, in insulating against external heat or cold, it will be found that consideration of radiation is of first importance. In tropical countries the value of a covering which will reflect most of the heat rays is well known; this has been exemplified in the case of oil storage tanks, which lose a considerable fraction of their contents per day by evaporation. When covered with aluminium paint or foil the loss is trifling by comparison.

As a good reflector is a bad radiator, aluminium when used for exterior cladding in cold atmospheres retards the flow of heat from the building.

Where heat insulation without strength is wanted, aluminium foil is inserted in an air space inside the wall or roof panels, and has been found remarkably effective and cheap. Typical figures for conductivity are given in the Table opposite.*

* Conductivity is expressed in terms of B.Th.U. per hr. per sq. ft. per in. thickness per 1°F. temperature difference. See also pp. 71–2, etc.

Conductivity of Various Building Materials

Slab cork	0·3 average
Slag wool	0·35 average
Glass silk	0·2 to 0·3
Cellular rubber	0·3 to 0·4
Eel grass	0·31 to 0·34
Cellular concrete	0·49 to 0·9
Common timbers	0·81 to 1·11
Asbestos slabs	0·33 to 0·37
Wood Fibre Board	0·38 to 0·41
Plaster Board	1·1
Asbestos Cement Sheeting	2·0 to 3·0
Concrete with gravel aggregate	6·7
Concrete with lightweight aggregates	1·1 to 2·3

Single layer Aluminium Foil in 1-in. air-space as low as 0·25.

Kitchens

At present, many kitchen layouts are being designed and new materials are being critically reviewed and tested in order that full advantage may be taken of their unique properties. If these are combined with advanced ideas on servicing and planning, the future kitchen will not be merely the pre-war type with disconnected improvements here and there, but a well-balanced, neat and wholly economic unit.

In these investigations, aluminium alloys are receiving much consideration and an all-aluminium kitchen has recently been produced.

Practical application has already recognised the suitability of these materials for many purposes, but data are still being sought on such items as sinks. For instance, wash basins of aluminium alloys have been fitted in aircraft and ships for some years and given satisfactory service, but domestic sinks are now under investigation.

In aeroplanes and marine craft of all types, aluminium alloys have been used extensively for fuel and oil tanks, lockers, sinks, doors and cupboards; these uses suggest similar applications and extensions in the home.

Lockers and cupboards in aluminium alloys were adopted with great success before the war by at least one very well-known multiple caterer. The metal is non-toxic (hence its widespread applications in dairies, breweries, etc.) and food may be stored with absolute safety. Such cupboards may easily be kept perfectly clean whether the metal is anodised or is untreated. Other advantages are that they may be easily moved, are vermin-proof and present a faultless exterior.

The kitchen requires an assortment of lockers and cupboards for enclosing food, tableware, laundry and cleaning utensils, etc. and the use of aluminium alloys for these would seem obviously desirable.

Construction may be of sheet aluminium of requisite stiffness pressed and stretched to the required contours with stiffening ribs incorporated ; an alternative is to use a sandwich board made up of a core of material acting as a base, such as plywood or cork, faced on both sides with aluminium alloy. In the past, the former method has been more generally employed, but of late the production of sandwich boards with an interior base, allowing easier shaping, has given impetus to the use of the latter method.

The application of aluminium alloys to refrigerators appears to offer prospects of success, for here the insulation properties of the material may be utilized. Suitable alloys resist corrosion by most of the refrigerants.

Aluminium covering to table tops has been used for some years and an extension of application is to use the metal as the principal constituent. The surface may be easily kept clean and shows no staining ; its appearance is pleasing and the lighter weight is an asset.

Wall and ceiling panelling to kitchens may be treated very successfully by facing with aluminium alloys. Their use for such features as mouldings and junction strips, has long been appreciated.

Many kitchen fittings and utensils such as door furniture, lampshades, and pots and pans are too well known further to discuss.

Bathrooms

In the bathroom, the application of aluminium alloys to the walls and ceiling appears to have possibilities. This is encouraged by the variety of finishes available and to the ease with which the surfaces may be cleaned. With the improved insulation and ventilation proposed for houses, less condensation should occur ; in any case condensation on the surface of aluminium is less than on many other types of wall covering commonly used for bathroom walls.

Baths in aluminium alloys were used experimentally in pre-war days, and although the cost then prohibited any serious attempt to interest the public, this factor operates less to-day and aluminium alloy baths are likely to be used to a great extent. Bathroom wash basins, lockers and fittings, as to the kitchen, may be considered as quite suitable for the application of aluminium alloys.

Shower Bath Cubicles and Swimming Bath Fittings

It has been found that the employment of aluminium alloys for the facing of shower bath cubicles, enabling easy cleaning and tidying, is very success-

ful. The alloys have also found very useful service for swimming bath fittings of all kinds, as well as for roof glazing.

Canopies

This is an instance where four important properties of aluminium alloys, i.e., high strength, high corrosion resistance, pleasing appearance and facility of extrusion to almost any section, may be used to great advantage.

These qualities are found together in no other material used in canopies, in which either the conventionally shaped structural members are visible from below and camouflaged by some form of decorative treatment, or the whole of the structure is encased with a decorative and protective covering.

This cover has usually been of sheet steel, the maintenance of which is a continuous heavy liability ; while so rapid is the corrosion attack that inspection for corrosion must start almost immediately after fixing.

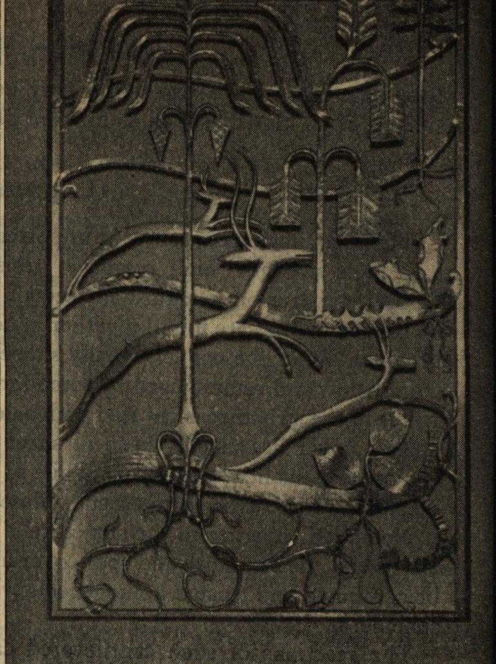
No added covering to the structure is required when aluminium alloys are used ; the structure and roof covering, together with all features, may be combined and treated homogeneously as a function in the architectural scheme.

The reactions of such cantilevered canopies in aluminium alloys are considerably less both on account of the much lower specific gravity of the alloys and of the absence of the covering steel.

General

Enough has already been accomplished in applying aluminium in building to demonstrate its practicability and to justify a considerable extension of its uses for every day needs.

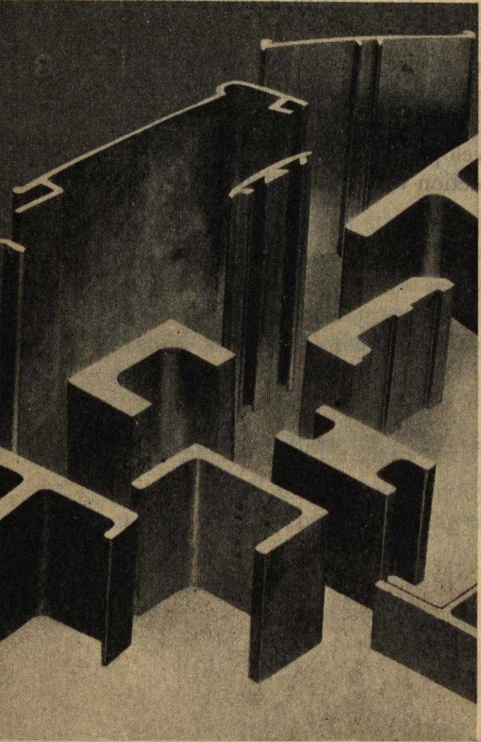
In conclusion it is stressed that expert advice is available and should always be obtained in connection with the choice of suitable alloys, the design of units or components, the method of manufacture and finishing process required. The Aluminium Development Association has been formed to deal with all enquiries in connection with building applications.

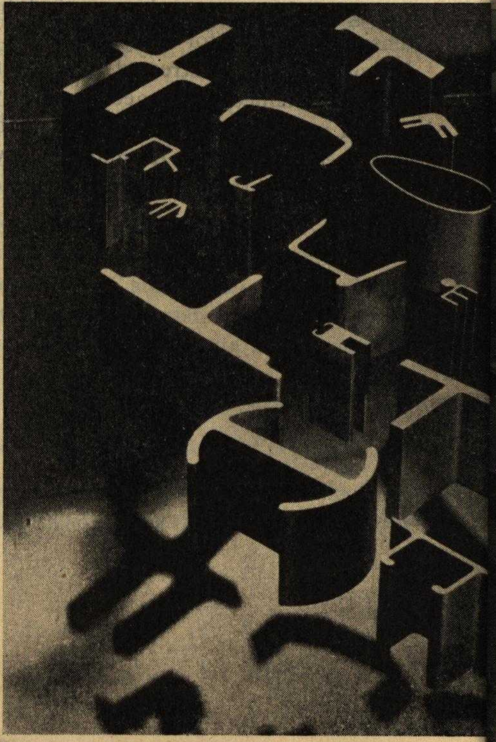


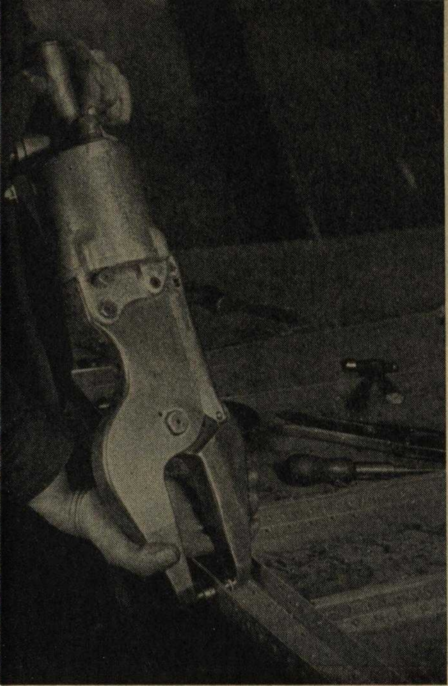
Two decorative uses of Aluminium :

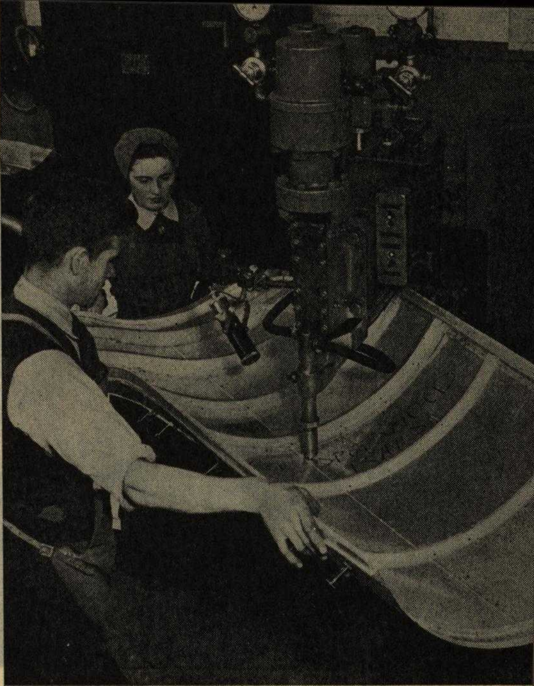
1. Colour anodized panel.
2. Hand-wrought grille.

3, 4. Some examples of extruded light alloy sections, showing the versatility of extrusion technique.



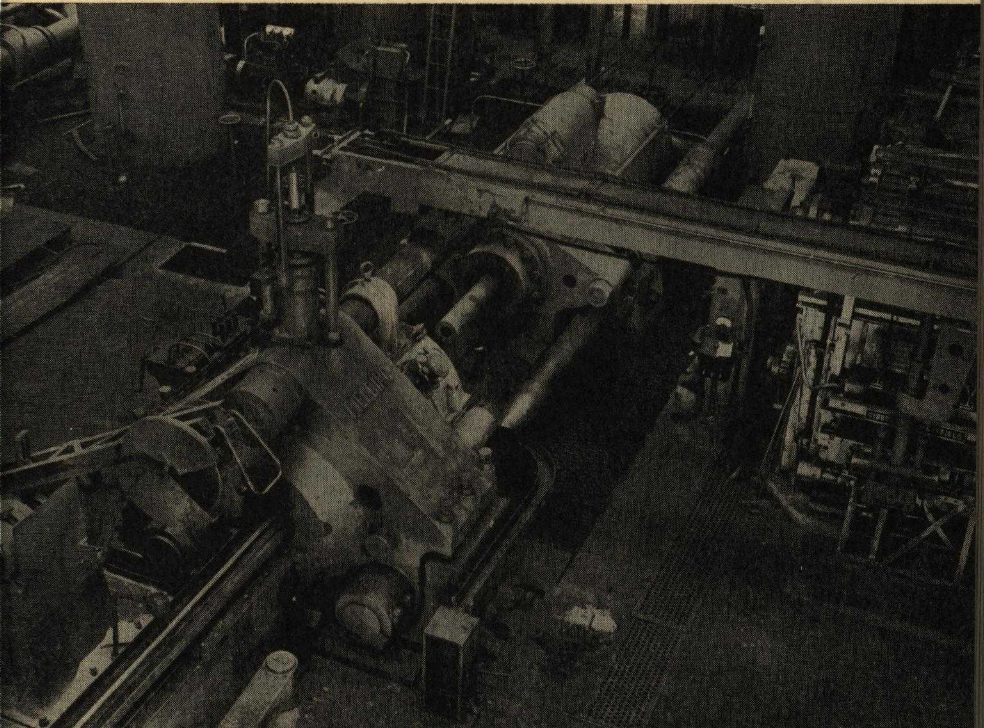


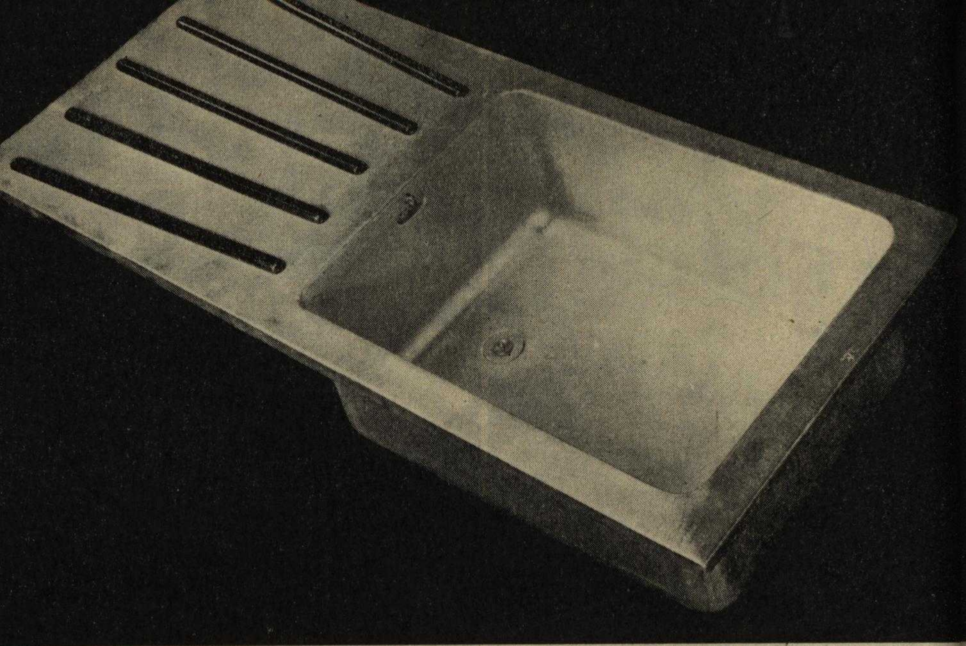




Some of the tools used in light alloy fabrication :

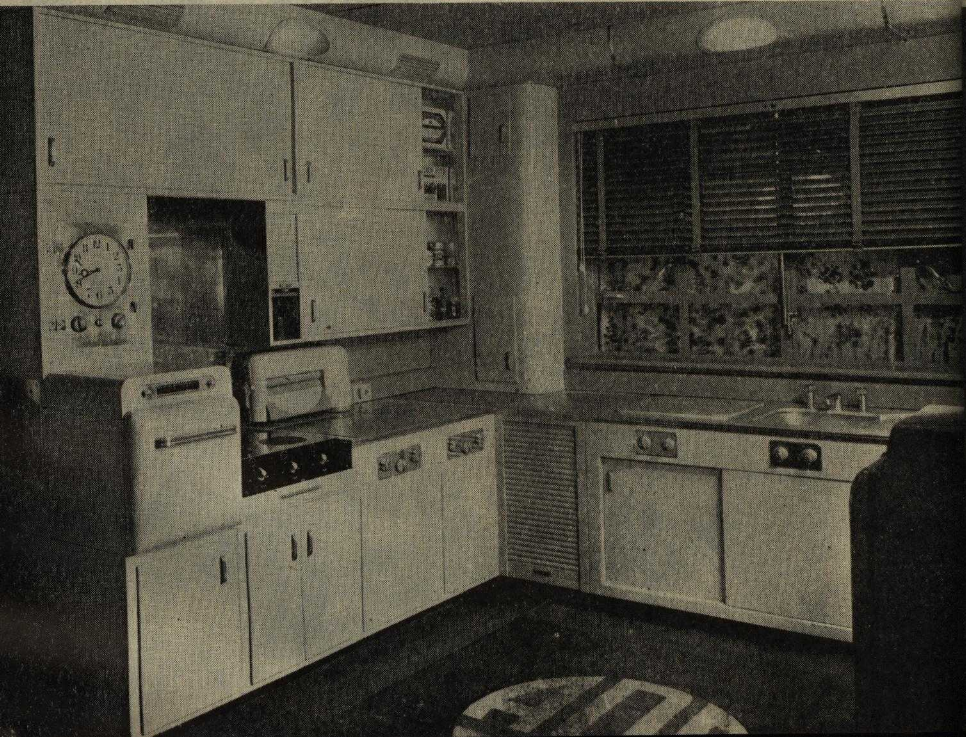
5. Compression riveter.
6. Spot welding machine.
7. An extrusion press, such as is used in preparing the extrusions shown in the illustrations opposite.

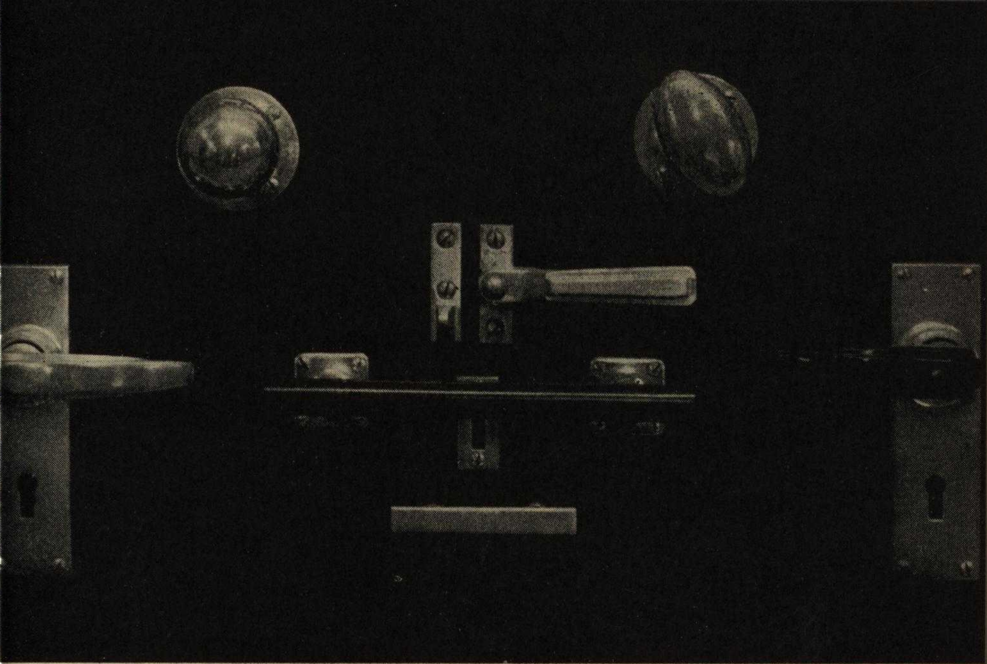




8. A sink unit pressed out of sheet aluminium.

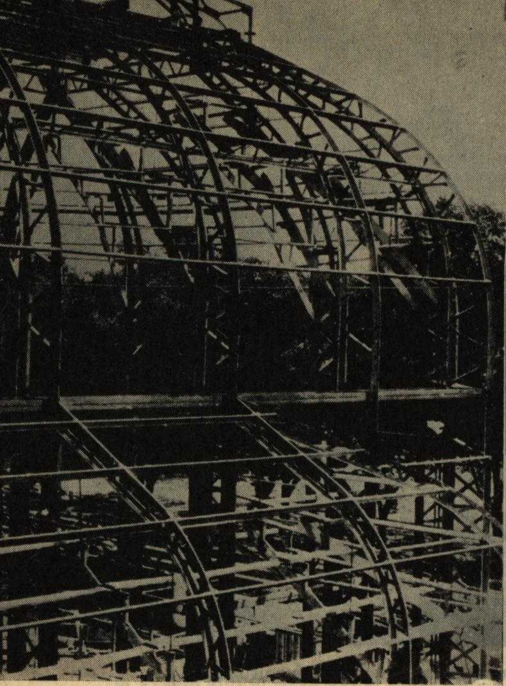
9. The all-electric light alloy kitchen designed by the Aluminium Development Association. Note the aluminium venetian blinds over the window.





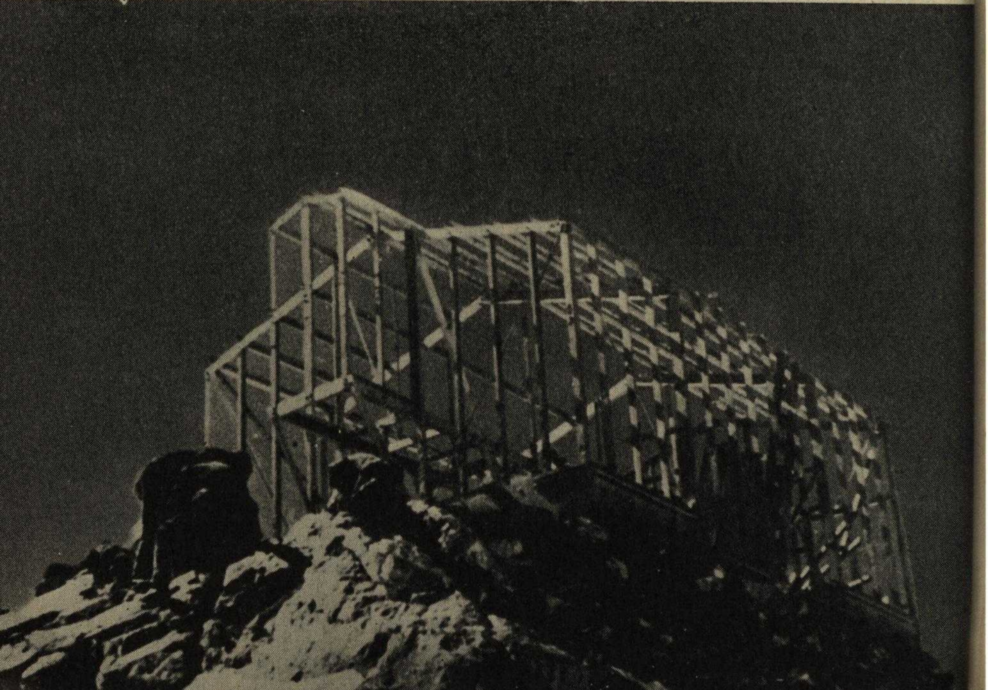
10. A few examples of standard aluminium door and window furniture.

11. An interior view of the A.I.R.O.H. house, looking from the kitchen into the living-room. For further views of this house, see Section VII, pp. 206-215.



Structural uses of Aluminium ; in both cases this material was adopted for special reasons.

12. Conservatory of the Botanic Gardens, Boston, U.S.A.
13. An early example of prefabrication—the Alpine Hut at the summit of Mont Blanc, during the course of construction. All materials had to be carried up by hand.
14. The framework of the same hut.



SECTION II

PLASTICS

Wherever enthusiasts foregather, the brilliant future of plastics is discussed. Perhaps prematurely, our generation is being given the title of " The Age of Plastics."

There is little doubt that some of the claims made on behalf of plastics are extravagant. But that does not detract from the very real contribution which plastics will be called on to play in providing the homes of the future.

Plastics are complex materials, and any description of their uses and relative merits is correspondingly involved. The unwieldy names of many of the plastics materials should not deter the reader. In their paper, Dr. Dunning and Mr. Wiseman have succeeded in unravelling the tangled skein and in presenting a continuous thread of elucidation.

The authors do not suggest that plastics provide a solution to all the problems of building and clothing a house. They point out some of the weaknesses which are still common to almost all types—their excessive deflections under load, their tendency to creep, their brittleness, the relatively narrow range of temperatures within which they can be used. It is probably still true to say that, apart from their uses in the production of small articles such as door furniture and electrical fittings, the principal uses of plastics are for painting and to enhance the properties of older materials like wood.

This does not preclude the rapid development of more ambitious uses for plastics. Already the range of properties is being rapidly extended, and the authors envisage a time when the existing shortcomings will be removed by research. Meanwhile, through their valuable qualities and through their colourful and practical appearance, plastics materials are already an important factor in the building trade.

PLASTICS

By

W. J. DUNNING, M.B.E., B.Sc., Ph.D. and L. A. WISEMAN, B.Sc.

INTRODUCTION

ALTHOUGH plastics have been used by the building industry for many years in the form of coatings, mouldings and bondings, their application is still in its infancy. Intriguing speculations on their possible uses have been made by many enthusiasts, and under the impetus of war developments have taken place which make many of these speculations seem less extravagant, though others may never be anything but dreams. Undoubtedly, plastics are most promising materials for the future, but their versatility in the past has encouraged exaggerated estimates of their future rôle. A sound evaluation of their prospects is not rendered any easier by the ever increasing number of plastics products and the ever widening range of their properties. This growing complexity is due to multiplication of the uses for which plastics are required and the development of special plastics for specific purposes. The layman and occasionally even the expert are confused by this diversity. Whilst in the early days plastics were considered to be materials which could be used for every purpose, the limits of their range are now being learnt. Plastics are modified and their applications selected so that their shortcomings are not important, and these will be removed by research.

Despite the continuous improvement in their properties, plastics still retain certain limitations. The traditional materials for building—wood, stone, glass and metal—also have their limitations, intrinsic in them and not readily modified. The architect has become accustomed to designing and working within these limitations. The grain in wood, the texture of stone, the fragility of glass, the weight of metal, must always circumscribe the architect's imagination. Plastics enrich his resources by offering a new range of properties and these may be modified to meet varying requirements. The time may come when the architect will specify the properties he requires to realise his unhampered conception, and the chemist and technologist will supply the material required.

It is often emphasised that plastics must not be regarded as substitutes, but it is natural, when a new material is discovered, to compare it and describe its properties in terms of familiar substances. It is also natural that the first uses to which it is put are to replace some of the earlier

materials to which it approximates. As experience of the new substance accumulates, it is seen to have unique characteristics of its own, which can be exploited in new ways of fabrication. The new material is now no longer merely a substitute, but takes its place alongside traditional materials. Such, in general, has been the story of the development of the use of plastics. First used to substitute and supplement materials such as bitumen, shellac and fossil gums, their ease of fabrication, transparency, translucency, toughness, lightness and colour offer new possibilities to industry.

To some extent there is bound to be competition between the old and the new, and where the new material offers some advantage it will replace the old. The usefulness of the old material, however, is often enhanced when it is used in conjunction with plastics. New properties are conferred upon it, disabilities are removed, and virtually another new material is created. Such is the case of wood. Combination with plastics and the use of plastics techniques produce resin-bonded plywood, impregnated and densified wood. Glass fibres and plastics are wedded in laminates to give remarkable properties. Some plastics are employed to give desirable finishes to textiles, others are used for bonding to metals.

TYPES OF PLASTICS

A distinction must be drawn here between a plastics material and a plastics product. The first is used in producing the second. More than twenty types of plastics material are in production, and these may be divided into two main types, the thermosetting and the thermoplastic, with a subsidiary group, the casein plastics.

The behaviour of the thermoplastic materials may be understood by considering the properties of the group's oldest member, bitumen. On heating, this material softens and becomes mouldable. In this state it can be shaped and on cooling it again hardens and retains its shape. This process of softening on heating and hardening on cooling can be repeated again and again. Because of this property, an economy is possible, since scrap material can be collected and re-used. Clearly, materials made from thermoplastics are unsuitable for uses in which they may be exposed to heat. The thermoplastic group is extensive and includes the following :

Cellulose nitrate ;
Cellulose acetate ;
Cellulose acetate-butyrate ;
Cellulose triacetate ;
Ethyl and benzyl cellulose ;
Polymethylmethacrylate ;
Polystyrene ;
Polyvinyl chloride and acetate ;
Polyvinyl butyral and acetal ;
Polyvinyl alcohol ;
Polyvinylidene chloride ;
Polyethylene ;
Polyisobutylene ;
Nylon.

The thermosetting plastics are powders which, under the action of heat and pressure, become mouldable and can be pressed to shape in heated moulds. While the plastics are under these conditions of heat and pressure, irreversible chemical changes are taking place, with the result that the material hardens while still hot, and a fundamental change occurs which alters the properties and character of the material. This process is referred to as "curing." Unlike the thermoplastic materials, cooling and subsequent reheating will not restore their mouldability. The principal members of this class are the *phenol-formaldehyde* and *urea-formaldehyde* plastics, but *phenol-furfural* and *melamine-formaldehyde* are of growing importance.

PROCESSES FOR MOULDING AND FABRICATION

The thermoplastic products may be converted into strip form by extrusion through a heated orifice or die. The machine may be compared to a sausage machine and consists of a heated tube containing a closely fitting screw, the pitch of which diminishes towards the discharge end. At this end the plastic is forced by the screw through a die. By feeding the plastic into the other end, a continuous strip may be obtained. By varying the shape of the die opening and hence the cross section of the extruded strip, fibres, rods, tubes and many fancy shapes are possible. Recently, this technique has been extended to thermosetting plastics.

By forcing the hot fluid material through a nozzle into a closed mould, intricately shaped products may be formed. The mould is kept cool by circulating water, and after the plastics moulding has been cooled sufficiently to harden it, the mould is opened and the moulded part removed. This method is called injection moulding and is extensively used for thermoplastic materials, but it has been recently applied to thermosetting materials as well. The cost of many plastics mouldings has been considerably reduced by the development of injection moulding in recent years.

Thermosetting plastics are generally moulded either by compression or transfer moulding. Compression moulding makes use of hydraulic presses by which high pressures (one to four tons per square inch) are exerted on the plastics material in the heated mould. The heat and pressure make the plastics material fluid, in which state it is compressed to a proper density and forced into all parts of the mould and cured. Compression moulding with some materials tends to produce a thick fin at the parting line where the mould opens, and shapes which have small holes and are otherwise complicated are difficult to mould by this method. An improved process (transfer moulding) is made use of which is a combination of compression and injection moulding. The thermosetting plastic is pre-heated outside the mould to a temperature at which it becomes

fluid, but which is below the temperature at which it cures rapidly. It is then forced into the heated mould and, since it is uniformly fluid, flows freely into the contours. Pressure is maintained until curing has been completed. Since the mould is closed under pressure before the material is loaded into it, the fin at the parting line is negligible.

The thermosetting plastics are not used "neat" for moulding but contain finely or coarsely divided materials which are called fillers. Whilst fillers are used to dilute and economise the relatively expensive plastic materials, they confer desirable properties on the moulded product. The filler used for general purposes with the *phenol-formaldehyde* resins is wood-flour, but cotton, chopped cloth or canvas, chopped cord, asbestos, metallic powders and silica may all be used to confer special properties on the product. The purposes for which *urea-formaldehyde* plastics are used normally call for a filler of pure wood cellulose, which is wood from which all materials other than cellulose have been removed by chemical treatment. The thermoplastic products can be used in conjunction with fillers, but generally the "neat" plastic is used.

A new technique for moulding large articles has been developed in which a mixture of wood pulp and a solution of resin is drawn by suction on to a wire mesh, gauze or perforated metal sheet which has the approximate shape of the finished article. The spongy layer deposited on this screen takes its shape and is called the preform. The preform is removed from the screen and is subjected to heat and pressure in the finishing mould. By forming the moulded shape before the final application of heat and pressure, stresses are eliminated in the finished product.

By modifying the chemical reaction between the phenol and formaldehyde, liquid products can be produced which may be poured into moulds and cured by subsequent baking. Since pressure is not required and moulds may be made from lead, this casting process is an inexpensive one for making simple shapes. Such cast phenolics may or may not contain fillers. Rods and tubes of circular and fancy cross-section may be cast in the same way. Certain thermoplastic materials such as *polymethylmethacrylate* may also be cast, though the technique is different.

Sheets of thermosetting plastic can be formed by casting in moulds or between plates of glass. In another process the liquid resin is partially cured in flat, open moulds until it has a rubber-like consistency. In this partially cured state it can be sliced into sheets of a desired thickness, after which the curing is completed by further heating. Slabs of thermoplastic materials, such as *cellulose acetate*, may be cut into sheets by the same slicing process.

An excellent example of the combination of plastics with the older materials, whereby their properties are improved, is given by laminated products. Great quantities of laminated sheets, tubes and rods are manufactured by combining plastics with paper, cloth, canvas, asbestos, glass

fabric and wood. In the manufacture of these materials, the phenol and formaldehyde are allowed to react chemically to produce an intermediate soluble product. This is brought into solution in alcohol to form a varnish. The paper or other sheet material is impregnated with this varnish and allowed to dry. These treated sheets are superimposed in a mould and hot pressed into flat sheets or simple shapes causing any remaining solvent to escape and the resin to flow. The resin cures and bonds the adjacent sheets together. The resin content of the laminated material may vary from 20–80 per cent. *Urea-formaldehyde* resins can also be used in a similar way and possess the economic advantage that they require only water as the solvent. The properties of the laminates are modified considerably by the sheet material which is used. The laminations need not all be of the same material. Thin veneers of wood, metal, or a double coating of plastic can be used on the outer surfaces as facings. Laminated tubes are made by winding the varnish-treated paper on steel mandrels of the required dimensions. In one process the wrapped mandrel is placed in a mould and curing brought about by heat and pressure. In an alternative process, the hot, treated paper, as it winds on to the mandrel, is pressed by rollers. It is necessary, in this case, to complete curing by an after-bake.

Of special importance are those laminates produced with thin veneers of wood. Here the best qualities of both wood and plastics are combined. The rotary-cut wood veneer is soaked in a solution of the phenolic resin and impregnation is assisted by applied pressure. After drying, these treated veneers are assembled on top of each other in a press and heat and pressure are applied, under which conditions the resin is cured and bonding of the veneers occurs. The pressure is maintained while the laminate is cooled in order to prevent warping. Since the resin has penetrated into the spongy walls of the wood cells the result is a homogeneous product which has acquired solidarity and density. The amount of resin used is only about 20 per cent of the total weight but this is supplemented by about 20–25 per cent of lignin which is already in the wood, and which may be regarded as a natural plastics material.

In a rather simpler process a solution of the resin is spread upon the veneers by rollers. The solvent is allowed to evaporate and the veneers are stacked and subjected to heat and pressure in a press. The resin is cured and glues the veneers together. Considerable penetration of the wood structure by the resin occurs before curing hardens it.

A third process dispenses with the spreading of the resin solution and makes use of thin sheets of tissue paper previously impregnated with resin and partially cured. These films consist of about 30 per cent paper and 70 per cent resin. The wood veneers are interleaved with the glue film and the whole assembly is then hot pressed. This process gives a product in which there is a smaller percentage of resin.

The similarity of these processes to plywood manufacture will be apparent. Ordinary plywood has been manufactured for the last 60–70 years by glueing an odd number of veneers or plies together under pressure with animal or vegetable glues. In recent years glues composed of plastics resins are replacing the natural glues and the resemblance is even closer. The chief difference is the pressure which is used, and it is preferable to use thinner veneers for the laminated woods than are necessary for plywood. Plywood and the laminates differ widely in specific gravity ; that of the plywood is close to that of wood (about 0·5), whilst the specific gravity of a plastics laminated wood may be as high as 1·35, since pressures of the order of 1,500 lbs. per square inch are used in the curing.

Plastics products have become known to the public hitherto as relatively small moulded articles. It seems likely that, in the form of moulded components, they will make an important contribution to the extensive housing programme contemplated in the immediate post-war period. Prior to the war, one of the main uses of plastics was for moulded electrical fittings. They also found extensive household use as door-furniture, in kitchen utensils, and as toilet accessories. For over ten years flushing cisterns have been made from the natural plastic bitumen ; improvements in the water-resisting properties of synthetic plastics have enabled them to be used for components which are submerged in water, such as sink stoppers, flush valves and flushing cistern floats. It is probable that the great demand for such articles will be partly satisfied by plastics moulding, which lends itself so readily to mass production.

Some people still consider that articles produced by mass production are aesthetically unsatisfactory. In the case of plastics, poor design has contributed further to this attitude. The use of the wide range of plastics materials, allowing an extensive choice of colour or colour combinations, all degrees of transparency, surface finish and texture, permits variety even with a single mould design. Yet the use of colour can never compensate for shortcomings in design. The design of articles in plastics can contribute something besides utility to the home, and a combination of function with aesthetic appeal could set a new standard of domestic comfort and beauty. The virtue of plastics is that the work of the best designers can be made available to every man.

The design of a plastics article must take account, not only of its purpose and appearance, but also of the technique of moulding. The mould is machined and cut from steel, and therefore an intricate design increases the cost of the mould. Trends in modern industrial art are away from over-elaboration in design and this is encouraged in the case of plastics manufacture by the economy of adopting simple moulds.

Besides design and fabrication of the mould, there are other factors which determine the cost of the finished article. These are the cost of the plastics moulding material, the cost of moulding and the cost of finishing

the article. The larger the number of articles over which the cost of the mould is spread, the smaller is the importance of this in the final cost of the article. The average cost of plastics moulding powders is about one shilling a pound ; this means that, in comparison with other structural materials, plastics are expensive. However, their specific gravity is low, ranging between 0·9 and 1·7, and this advantage must be taken into account when assessing the price. As production expands, the cost of the more expensive plastics materials may fall. A good design reduces the finishing costs, such as removal of fins, buffing, polishing, machining and possibly surface decoration. Some saving in final cost can be achieved by accepting the surface imparted by the mould and eliminating polishing operations.

The post-war building programme will call for a very large output of plastics mouldings and their supply may be undertaken not only by reputable firms but by others as well. To avoid disappointment and to maintain the standard of mouldings, it is wise to undertake a complete inspection of random samples of the moulding powder and also of the final mouldings. The tensile and impact strengths, water absorption, electric strength and other properties of a test moulding from the powder should be measured. The final mouldings should be inspected visually for surface smoothness, absence of blisters, uniform gloss and colour, fin marks and porosity ; if the contract specifies sizes these should be checked and the completeness of the cure tested. The British Standards Institute has drawn up some standard specifications for the properties of plastics materials.

The design of the mould should aim at producing the finished article, since all finishing processes are expensive and should be avoided if possible. Nevertheless, should it be necessary to incorporate holes in the sides of the moulded piece, it is better to omit them in the mould design and to drill them in the moulded article, since these holes add to the cost and difficulty of moulding. It is often possible to dispense with a complicated mould by machining operations on moulded articles of standard design. Plastics materials are also supplied in stock shapes such as rods and tubes of simple or complex cross section, blocks and sheets. All the usual operations such as turning, drilling, sawing, milling, tapping and threading can be carried out on these materials, using standard tools with minor modifications in tool design and cutting speeds. They may be joined by glueing with special glues or by means of screws and rivets. Many of these materials are too hard and brittle for nailing. Strips and sheets up to certain thicknesses can be punched. A low temperature is to be preferred for this, but for thicker sections it may be necessary to heat the sheet first. These methods of fabrication, allowing the free play of craftmanship, are suitable for the production of small numbers of articles which would not justify the cost of a mould.

The method of producing cast plastics limits the lengths of the rods, etc. to about 18 inches. Very much longer pieces, with a wide variety of cross-sections, can be obtained by extrusion, usually of thermoplastic material. These may be cut into slices which, after buffing and polishing, form the finished product. In this way, numbers, letters, towel rollers, brackets and other small fittings can be rapidly produced. Extruded strip may be used for decorative trim for the edges of panels and furniture. Shelving, stair rods, curtain runners, picture rails and wainscoting are other applications. Pipes and tubing are available for plumbing and decoration, and banisters of attractive cross-section have been reported.

PROPERTIES OF PLASTICS

So many considerations present themselves that the architect who proposes to design in plastics would be well advised to seek advice from the plastics technician. Most manufacturers of plastics have service departments which will readily co-operate. Together with the potentialities of plastics, there exist certain intrinsic limitations, but with a little patience the architect can acquire a working knowledge of these factors. Extensive data on the properties of plastics are available and these cover mechanical, thermal, chemical, electrical and optical aspects. Whilst in a single class of plastics material these properties may range between wide limits, certain broad generalisations may be made about the classes themselves.

Plastics have the same mechanical properties as other structural materials but difficulty arises in that the values of these properties are very different and in unfamiliar combinations. For articles which may be subjected to rough handling toughness is required. It seems that the best indication of this is the impact strength, which is measured by the energy absorbed by a swinging hammer in breaking a strip which may or may not have a narrow groove or notch cut into its side. A selection of phenolic plastics made by Durez shows the following range of impact strengths. A high grade general purpose plastic with a filler of wood flour has a value of 0·44 ft. lbs., a medium impact material 1·20 ft. lbs., and a very high impact material 4·4 ft. lbs.* For telephones a medium impact material is required, whereas a general purpose plastic will be adequate for wall switches. Urea, vinyl, methacrylate and polystyrene plastics have impact strengths between 0·2 and 1·5 ft. lbs., whilst cellulose acetate plastics are tough and have impact strengths from 1 to 6 ft. lbs. For special purposes, materials with impact strengths of 40 ft. lbs. and even higher are available.

The tensile strengths of plastics lie in the region of 2 to 5 tons/sq. in. Recent developments have produced laminated materials with tensile strengths of 20 tons/sq. in. and products with even higher values have

*The Americans employ a different type of impact test from that used here, and care is necessary in comparing the results.

been reported. These values compare favourably with the value of 5 tons/sq. in. for Canadian birchwood, but are considerably less than the value of 80 tons/sq. in. for steel. The low density compared with steel reduces this difference, since on a weight for weight basis the tensile strengths then become comparable. This more favourable aspect has promoted much discussion on the possibility of employing plastics for structural load bearing members. The fact that thermoplastic resins soften at relatively low temperatures precludes their use in load bearing members, since the structure would collapse in the case of fire and therefore only thermosetting resins can be considered in this connection. Considerations of tensile strength further restrict the choice to either laminated materials or plastics which are reinforced with fibrous material. H. V. Potter* has compared a 15 ft. span solid oak beam capable of carrying a dead load of 1,000 lbs. per ft. run with, first, a solid beam of a fabric based plastic and then two beams of hollow cross-section, one of the same fabric based plastic and the other of a paper based plastic. His calculations show that in all cases the plastics beam undergoes greater deflections than the oak beam. This excessive deflection could be prevented by using a thicker beam, but such a beam would be many times stronger than necessary, and the cost much higher. Modification of the cross-section of the beam and the development of plastics with higher elastic moduli may overcome this difficulty of excessive deflection. R. J. Schaffer† has also considered this problem. He concludes that, even if a plastics material with a suitable modulus of elasticity, 8,000 to 9,000 tons/sq. in. for a tensile strength of 13·4 tons/sq. in. could be made available commercially, it would have to be sold at from 3d. to 5d. a lb. in order to compete with wood and steel. Another disadvantage is that plastics are lacking in ductility. Ductility provides a means whereby stress concentrations may be smoothed out. Without this ductility dangerous stress concentrations in any one member may arise. This lack of ductility makes plastics rods unsuitable for the reinforcement of concrete since any stress concentrations in the reinforced beam tend to the rupture of one rod after another. If there were a greater degree of ductility in the reinforcement the load would be distributed equally over all the rods. Meharg and Welch‡ have discussed the effect of notches in the surface on the breaking strength of plastics. Owing to the lack of ductility of plastics materials, such notches sharply reduce the breaking strength. An analogy can be drawn with the effect of surface scratches on glass. Here the reduction in strength due to a diamond scratch is not due to the glass being thinner at that point but because this discontinuity allows large stress concentrations to be built up so that a crack, once started, easily propagates. In a more ductile

*_Journal of the Royal Society of Arts_, LXXXVIII, p. 672 (1940).
†_Chemistry and Industry_, **61**, p. 357 (1942).
‡_Modern Plastics_, p. 117, Sept., 1944.

material this stress is relieved by flow. Materials such as glass and plastics which behave in this way are said to be " notch " sensitive. A rough guide to the order of merit regarding " notch " sensitiveness under static load is given by the dynamic impact resistance test of notched samples. Glass filled phenolics and compressed laminated wood are better than fabric filled phenolics and then come paper filled and wood flour filled phenolics. If plastic materials, which are " notch " sensitive, are used in constructional work, care must be taken to design the parts so that holes, notches, sharp inside corners and abrupt changes in cross-section are avoided in stressed parts, since these give rise to undesirable stress concentrations.

Table I gives values for representative plastics and structural materials for comparison with the figures suggested by Schaffer.

TABLE I

Material	S.G.	Tensile Strength tons/sq. in.	Compressive Strength tons/sq. in.	Modulus of Elasticity tons/sq. in.
Steel	7·85	80	75	14,000
Duralumin	2·80	25	20	4,500
Magnesium alloy	1·81	20	16	3,000
Spruce	0·5	5	2·5	650
Glass fibres	2·5	60	Very high	1,000
Hydulignum*	1·31	13·8	7·6	1,660
Fiberglas phenolic laminate	1·75	19–24	18–34	1,100
Gordon Aerolite	1·43	20	11	2,700
Polyvinylidene chloride (drawn)	1·7	27	—	—
General Purpose Phenolic	1·35–1·44	2·9–3·7	7–16	400
Nylon (drawn)	1·06–1·19	22–55	—	—
Polystyrene	1·06	2·3–4·0	2–5	240
Polythene	0·95	1·0	—	—
Polythene (cold drawn)	0·95	2·0–6·3	—	—

Hydulignum is an improved or high duty wood made by compressing thin resin coated birch veneers. Gordon Aerolite is a phenolic resin reinforced with cords of flax and, it is understood, improved versions have been produced. From Table I it will be seen that the mouldable plastics materials such as the general purpose phenolics, polystyrene and polyethylene compare very unfavourably with metals in strength even when the specific gravity is taken into account. When plastics are reinforced by fibrous materials such as wood cord or fiberglas, their strength approaches that of some metals. If the specific gravity is taken into account by comparing not the strengths directly but the ratios of the strengths divided by the specific gravity, the reinforced plastics are in many cases superior to the metals ; but for many purposes where space may be limited the in-

*The tensile and compression strengths are measured with the grain.

creased bulk of the plastics will be a disadvantage. Nevertheless, one may be optimistic that further advances may be along similar lines. Already plastics materials are being used in air, road and sea transport, where their lightness and strength to weight ratio are at a premium. Attention has been called* to the wide discrepancy between the actual tensile strength of phenol-formaldehyde plastics of about 3 tons/sq. in. and a theoretical estimate of about 300 tons/sq. in. It is possible that as a result of future research, tensile strengths will approach more closely to this theoretical value.

Apart from the use of laminated wood in stressed parts, there is very little experience of plastics in structural applications and much more work will be necessary under static and repeated stresses. Other factors which must be considered in this connection are creep and cold flow. The latter may cause any nuts, screws and bolts, which are locking plastics parts together, to loosen after prolonged service due to the plastics flowing away under them. Phenol-formaldehyde and urea-formaldehyde plastics undergo least cold flow, and for them it is small enough to be disregarded entirely, so long as the customary factors of safety are incorporated in the design. The vinyls, acrylates, acetates, polystyrene and other thermoplastics are not quite so satisfactory and they should not be used if more than moderate stresses are to be encountered.

Any consideration of the mechanical properties of plastics must take into account the effect of temperature. The majority of thermoplastic resins cannot be used safely above 140–200°F. without appreciable distortion. Two thermoplastics, the production of which is increasing, lie outside these ranges. Some grades of *polyethylene* have softening points above 230°F. and moulded *nylon* has a softening point of 450°F. Whilst the deformability of these plastics increases with temperature, their impact strengths also increase. This implies that they become more brittle at low temperatures, but this reduction in impact strength is not important in the range of climatic temperatures, and most plastics can be used down to –40°F. The tensile strength of *phenol-formaldehyde* and *urea-formaldehyde* resins decreases with increasing temperature and this should be borne in mind for use in stressed service. The effect of temperature on impact strength varies with the nature of the filler. The maximum operating temperature for a general purpose phenol-formaldehyde plastic with a wood flour filler is about 350°F., but with special fillers this limit can be raised considerably—with asbestos to 500°F., with fiberglas to 600°F. and with resin-bonded mica-splittings up to 1,000°F. In addition to the effect of temperature on the mechanical properties, the increase in attack by oxygen of the air must be considered and many applications will require consideration of the effect of temperature on other properties such as

Trans. Faraday Soc.*, **32, p. 3. (1936). E. K. Rideal; p. 3. J. H. de Boer, p. 10. R. Houwink, p. 122.

colour. For instance, at some temperatures the mechanical properties will be but little affected, although the material may become slightly discoloured.

ELECTRICAL APPLICATIONS

Small electrical fittings in plastics materials are familiar to everyone, and have been long accepted as structural accessories. Since these products are small and of simple design, they are very suitable for mass production by moulding technique, and although the majority of objects such as switches have been produced in rather sombre colours, they can easily be produced in every variety of colour without impairing their electrical properties. The electrical requirements are not rigorous in most household applications, so that the more expensive plastics such as *polystyrene* are not required and therefore phenolic plastics are mostly used. Should resistance to arcing be required, then *urea-formaldehyde* plastics have preference over phenolic plastics. During the war *polyvinyl chloride* in a variety of colours has been used to a very large extent as an insulating and water-resistant wire covering which is highly flexible and fire resistant. This choice of colours permits easy identification of the wire and since the colour is incorporated throughout the plastic and will not wear off, this should be of great service in installing electrical systems. Fans have been produced in which everything but the motor is in plastics. Here again, in comparison with metal fans, weight is reduced, appearance does not deteriorate as a result of atmospheric corrosion, and chance electrical shocks are unlikely.

COLOUR AND PLASTICS

One of the most outstanding features about plastics is the very wide range of bright colours and delicate shades available, which makes it easy to harmonize plastics with other furnishings in general colour schemes. On the other hand, this wide variety and the unlimited possibilities of disharmony it implies emphasise the need for restraint and artistic judgment. Hundreds of colours are available with intriguing names like coral, topaz, pale amber, peach and delphinium blue.

The colours may be introduced either as pigments or as dyes ; with pigments there is an increase in the reflection and diffusion whilst the transmission is cut down, because the particles of pigment remain discrete ; on the other hand, a transparent plastics to which a dye has been added remains clear. Bright, gem-like products of all tints are obtained by adding dyes to the transparent plastics, and pastel shades may be obtained by the addition of a white pigment. Transparent sheets may, in some cases, be dyed simply by dipping the sheet into a solution of a suitable dye. *Urea-formaldehyde* laminates and filled resins are very colourable and their

translucency gives beautiful pastel shades. The *phenol-formaldehyde* resins have an intrinsic amber-brown colour which modifies any added colour, and this limits their possibilities to the darker colours. Nevertheless, if wisely chosen, these more sombre hues can be very handsome and have a solidity and attraction of their own. In contact with alcohol and greasy foodstuffs the dye may come out of the plastics and, to counter this, special " non-bleeding " plastics are available. If the plastics part is exposed to strong sunlight, or heat, or excessive humidity or perspiration, the dye and resin must be chosen so that no deterioration occurs under these conditions.

Attractive mottled coloured effects are possible, the best known being the imitation tortoiseshell used in spectacle frames. Imitation onyx and marble have also been produced. The desirability of imitating the appearance of other materials is a matter of taste, but there can be no objection to such mottled effects if they are attractive in themselves and the purpose is not to deceive.

In all these cases the colours exist right through the plastics product, so that if it is slightly chipped or scratched the damage does not show up. However, the colouring possibilities are not limited to those in which every plastics unit is of a simple colour or uniform mottling. A compression moulding of one colour can be used as an insert for an injection moulding of another colour, the general effect being like that of a cameo brooch ; this is, of course, an expensive technique. Surface decoration and printing are now feasible. Special inks which themselves contain plastics in solution are applied to the surface by hand, by the silk screen method, by lithography, etc. The decoration on drying becomes part of the plastics, and cannot be removed without damage to the surface. Another possibility in the case of urea formaldehyde laminates is to insert a sheet of paper with the printing or decoration on it in the laminate ; in this way signs, instruction cards, name plates, pictures, and so on, can be incorporated in the laminate.

Luminescent pigments may also be used in conjunction with plastic materials and may be of two types : those with a long afterglow in the dark (phosphorescent) and those which glow only whilst light is falling on them and become invisible when the light is cut off (fluorescent). Phosphorescent pigments have been suggested for door knobs, house numbers, electric switches, kick plates, stair riser plates, etc., the visibility of which would minimise the inconvenience of a power failure, and fluorescent pigments for lighting shades to cut down glare, in wall coverings and in architectural trim. Since fluorescent pigments glow brightly when ultra-violet (" black ") light falls on them, they have been used in advertising displays. The price of such pigments, though falling rapidly, will not yet permit their general use but for many purposes they are worth consideration, especially if they are applied to the surface by a printing technique.

TRANSPARENT PLASTICS

In the form of celluloid, *cellulose nitrate* has been a familiar material for many years and can be considered as the first of the " organic glasses." Its transparent properties were made use of in photographic film and in motor car windows, first as sheets of celluloid and then as the sandwich between glass sheets, forming safety glass. Large quantities were used in the manufacture of toilet ware and novelties, spectacles etc., for which its ease of manufacture made it very suitable. During the last war cellulose nitrate was used as an aeroplane dope, and efforts were then made to find a similar substance which was less inflammable. This led to the manufacture of *cellulose acetate.* After the war it was found that cellulose acetate could be extruded through small holes into fine filaments ; these were spun into threads to form " rayon." Cellulose acetate was used for plastics moulding in the early thirties and is now the most used plastic for injection moulding, especially for moulding over die cast zinc inserts where the strength of the metal and the finish of the plastic are combined. In many ways it is similar to cellulose nitrate. Despite its inflammability, cellulose nitrate still holds its own by reason of certain advantages in ease of fabrication and superior water resistance. The poor water resistance of cellulose acetate has led to the development of *cellulose triacetate* (a cellulose acetate with high acetyl content) and of *cellulose acetate-butyrate.* These have higher resistance to water and excellent moulding characteristics, but cellulose triacetate is not popular commercially because of various technical difficulties, and cellulose acetate-butyrate has been developed principally in the U.S.A. Included with these transparent cellulose materials is regenerated cellulose, which is well known by its trade name, " Cellophane."

All these materials are " semi-synthetic " plastics and are chemical modifications of the natural product, cellulose. In addition to these transparent plastics, there are a number of others which are " synthetic " in origin. These are *polylmethymethacrylate* (trade names, Perspex and Diakon), the vinyl resins such as *polyvinyl acetate* and *polystyrene* (trade name Distrene). All these materials are transparent and possess crystal clarity and brilliance. Many of these " organic glasses " have become specially important during the war for their use in the gun-turrets, windows, domes, etc. of aircraft. Their low specific gravity (1.2, compared with 2·4 for ordinary glass), high light transmission and anti-shatter properties make them very suitable for this application.

However, it is very unlikely that they will compete with ordinary glass for general glazing purposes until their price is very much reduced and their scratch resistance is considerably improved. Some of the organic glasses are inferior in weathering properties, which disallows them for many applications. In particular, cellulose acetate loses its clarity if subjected

to fluctuating conditions of humidity. A standard test of the resistance of a plastics material to water is to immerse a sample in water for 24 hours, weigh the amount of water taken up, and measure the change in the dimensions of the sample. Cellulose acetate takes up 1–4 per cent, cellulose acetate-butyrate 0·9 per cent, polymethylmethacrylate 0·3 per cent and polystyrene nil per cent. Polystyrene and polymethylmethacrylate have very good resistance to weathering. The dimensions of the cellulose acetate test piece increase by 1 per cent after the test. This swelling may lead to buckling and distortion in cases where cellulose acetate is exposed to humidity, but it is much less important for others and may be neglected for polystyrene. Cellulose acetate butyrate has been used for twelve months in aeroplanes and has been uninjured by weathering. After six months' exposure to sunlight, polymethylmethacrylate shows no change in colour, transparency or clarity. The vinyls, too, are very resistant, but crazing and discolouration may occur with cellulose acetate under these conditions.

The organic glasses are stronger and tougher than ordinary glass, and where requirements of lightness and freedom from splintering justify the enhanced cost, they have been used for window glazing. Such applications are in communal kitchens where any broken glass may contaminate foodstuffs, in nurseries by reason of the fact that organic glass, if broken, does not have sharp cutting edges, and in power houses. For additional strength wire mesh may be used to reinforce transparent cellulose acetate sheet by laminating it between two sheets. This is very much more resistant to shock than similarly reinforced glass.

The organic glasses transmit ultra-violet and infra-red rays far better than ordinary glass and inexpensive cellulose acetate sheets have been produced for use in hot houses, sun porches, hospitals and nurseries. Polymethylmethacrylate and polystyrene have the property of "piping" light. If a rod or sheet is illuminated at one end or edge, the light is transmitted through and carried round curves and bends until it reaches the other end or edge, where it escapes. If the edge of a sheet is exposed to the light and letters or motifs are cut or sand-blasted on to the surface, the light can escape from the roughened surface and the sign stands out brilliantly luminous against a transparent background. Advantage has been taken of this effect to achieve new and original effects in sculpture, for which the ease of manipulation and working makes polymethylmethacrylate a medium of growing popularity.

Polymethylmethacrylate has been used for the interior decoration of public rooms in hotels and restaurants and on board ship and train, and its weather resistance and ease of cleaning would permit its exterior use. For these purposes it has been produced in blocks, sheets, rods, tubes and moulding powder. Complicated extruded mouldings and cast wall panels of cellulose acetate butyrate have been reported from the U.S.A.

To the architect, the organic glasses will be particularly useful where curved transparencies are required. There is less distortion of vision than in ordinary glass and they are more transparent. A distinct advantage over silica glass is given them by their ease of " forming," by which sheets may be bent or drawn into shapes having simple or compound curves. For this the sheet, which may be ¼-in. thick, is warmed to 220°F. in oil or in an air oven, where it becomes sufficiently flexible to be placed over a wood, metal or plaster form, and pulled into shape. It is allowed to cool and will then retain its newly acquired shape. A modified process employs a vacuum to suck the flexible sheet into shape and these thermoplastic sheets may be blown into a mould to form toilet floats, bottles, vases, etc. Transparent plastics have been used in furniture to produce mirrors, " invisible " chairs, bed ends,etc.

PLASTICS IN LIGHTING FIXTURES

For architectural lighting fixtures plastics have found very wide use and offer many advantages over silica glass at a competitive cost, especially in the case of small complicated shapes. Transparency is not usually required for lighting fixtures since it gives rise to glare. Instead, high light transmission is required with a high degree of scattering or diffusion to eliminate glare. For this purpose, small discrete fibres of purified cellulose are incorporated into the transparent organic glass. An alternative effect is achieved by sand blasting. Whilst the transparent thermoplastics such as *polymethylmethacrylate* have the advantage of high transparency, their property of becoming soft at about 160°F. may result in " creep " and distortion. The thermosetting *urea-formaldehyde* resins are used in preference, since they give uniform transmission and excellent diffusion. The safe temperature for continuous operation with these latter in lighting fixtures is about 170°F., though this may be considerably exceeded for brief periods. Continued exposure may cause the fixture to become brown. The design should take account of this and the plastics surface should be not less than 2½ in. from the filament of a 200 watt lamp or 4½ in. from a 500 watt lamp. A new synthetic plastics material, *melamine-formaldehyde*, can be exposed to much higher temperatures than the urea-formaldehyde.

Fluorescent lighting is being used on a rapidly growing scale in shops, restaurants and industry, but has not been used to any extent in the home, probably because of the blue green and purple colour of the light. It has a much higher efficiency than filament lamps and is very much cooler in operation. It can, therefore, be used in conjunction with thermoplastics materials such as cellulose acetate, polystyrene, and polymethylmethacrylate. These materials can be used in the fashion described below for the urea-formaldehyde sheets, or the materials may be extruded into

lengths of small cross-section which may be interlaced and woven to form the fixture.

The urea-formaldehyde plastics may be moulded into shape by compression moulding and reflectors 25 in. in diameter have been produced in this way. Alternatively, sheets laminated with thin paper for the diffusing material may be heated and shaped into simple curves by forming. A large variety of distinctive designs can be made from the laminated sheet alone and in combination with transparent sheet by machining processes, sawing, punching, etc. These sheets are available in every colour and can be decorated in many novel and attractive ways, more easily than with silica glass. The moulded lighting shade can be moulded with fluted, spiral and other designs in which the thickness is varied. These variations show up as patterns of light and shade, due to the varying light transmission. With all these possible techniques, the ingenuity and artistry of the designer are almost unhampered in producing smart and stylish designs. Since the plastics shade is usually only 15 to 20 per cent of the weight of a corresponding glass shade, the ceiling supports need not be so substantial, or, if they are, larger shades can be used. The weight of the shade is important in the design of floor lamps if these are not to be top-heavy. Their lightness contributes to safety, since they are easily handled and fitted. If they fall, less damage is done, and being tougher they are less liable to break. Unlike glass, they do not form sharp edges, and so broken pieces are much less dangerous. These plastics shades have found application in food factories, nurseries and schools, and especially in railway coaches, motor cars, aircraft and ships. They are also used as fan lights, ceiling lights, corner and trough lights.

Urea plastics can be used in indirect lighting fixtures, since they can be obtained in a form with high efficiency of reflection.

LAMINATED PLASTICS

Laminated plastics sheets are usually available in various sizes up to 8 ft. by 4 ft. and of various thicknesses from 1/32-in. up to 2 and 4 in. They are prepared by bonding sheets of paper or cloth by means of a thermosetting resin, usually either *phenol-formaldehyde* or *urea-formaldehyde*. There is an extensive range of colours, either solid or mottled. The phenol-formaldehydes are dark-coloured, but if more delicate colours are wanted a surfacing layer of light-coloured urea-formaldehyde may be incorporated during the pressing, or the entire bonding may be urea-formaldehyde. These latter are very suitable for decorative work and for lighting. In the same way, the light-coloured *melamine-formaldehyde* may be used as a surface-coating which also, in comparison with urea-formaldehyde, improves the heat, water, and weather resistance. The surface can be supplied with a highly polished, a satin, or an imitation

leather pattern such as morocco finish. The surface is permanent and does not require refinishing or painting unless used out of doors. Laminated plastics are hard and tough and resist wear; in fact, they are used for gear wheels, rolling mill bearings and motor car clutches. They absorb sound and so assist in insulating against noise. Water is not absorbed by them, they are impervious to dilute acids, many grades are not attacked by dilute alkalies, and they can be easily cleaned. Since they have a low heat conductivity, vapour condensation does not occur on them and they assist heat insulation. They are finding growing use in refrigerators; and for such uses where plastics may come into contact with food, odourless laminates are available which neither assimilate nor produce odours. They are impervious to attack by mildew and insects, and their hygienic qualities recommend them for use in hospitals.

Such plastics sheets have been used increasingly for partitions, flush door surfaces, cupboard doors, kitchen cabinets, shelves, window sills, skirtings and kick plates, inlaid murals, table tops, counter tops, furniture, bath fronts, splash boards and other interior surfaces. Where an attractive permanent finish and a good serviceable structural material is desired, they have found extensive use in hotels, restaurants and other public buildings, and in facing telephone kiosks. The colour of walls panelled with them might be too permanent for the home, where an occasional change is welcome, but this would not be a disadvantage in flats, where different occupiers succeed each other more frequently. Nor would it matter for special surfacings in lavatories, bathrooms, kitchens and so on.

Laminated plastics have been used extensively for table tops, for which their resistance to alcohol and to burning by cigarettes may be increased by the inclusion of a thin sheet of aluminium foil as one of the laminates, just below the surface. In this way the heat of the cigarette is conducted away and the cigarette will burn out without blistering or damaging the surface. The surface may consist of a thin layer of urea-formaldehyde followed by either thin veneers of decorated wood, by printed and decorated sheets of coloured paper or by fabrics. All of these are bonded to the core sheet by synthetic resin. In this way the beauty of the wood and the textural appearance of the fabric are retained and combined with the smoothness and wear resistance of the laminated plastics.

Plastics sheets are subject to dimensional changes with change in temperature and humidity. The magnitude varies with the type and the percentage of resin and with the nature of the laminating material. Although the information available is slight, it seems that in the laminated materials likely to be used for surfacings, the dimensional changes are small. Nevertheless, to avoid warping and distortion the materials should not be glued together and to the support, but they should be fitted with small gapsin between to allow for slight expansion. One method of fastening employs self-tapping screws or nails; these cannot be used

unless holes are first drilled in the plastics sheet. There should be a loose fit to allow for expansion and contraction. The heads of the screws or nails should match the laminate, or a strip of plastics trim or a chromium plated band of metal may be used to cover the joint. Another method of fixing employs a decorative metal cover strip in which the sheets are held by the spring of the metal. In another suggested method, a steel channel clip holds the panels together. In a fourth method which has been described* the panels were applied to wood (furring) strips and wood grounds which previously had been attached to the masonry walls. All means of fastening the panels to the walls are concealed by a progressive system of tongue and groove joints.

The use of plastics laminates is not confined to flat surfaces ; numerous shapes can be obtained. The first method was to cut the impregnated cloth or paper to the required shape and insert it in a compression mould of the same shape as the final object and bring about moulding and curing. An example of this is a canvas laminated aeroplane pilot's seat. A newer method starts with the cured laminated sheet and forms this into simple or compound curves. The thermosetting resins such as phenol-formaldehyde which are used in the laminates have been differentiated from the thermoplastic resins by their reaction to heat. Thermoplastic resins were defined as those which become soft and pliable on heating. Thermosetting resins are those which are infusible. Yet this classification is only one of degree, since it is found that the thermosetting resin laminates have a degree of pliability at higher temperatures. The sheets can be heated in an oven to a temperature rather higher than that at which they are cured and they then become sufficiently plastic. In this condition the laminate is quickly inserted into a press with wooden forming dies and pressed into shape. When cold, the shape is permanent. Sharp bends can be made in the material without fracture, but the inside diameter of the radius should not be less than the thickness of the material. In this way, a number of curved parts may be produced with negligible mould costs. The method was developed in the aircraft industry for moulding large parts of aeroplanes ; one example is the fairing of a chin turret which measures 50 × 40 in. An advantage of this process is that sheet metal forming technique and presses can be used. Now that the war is over, it is to be expected that this method will be applied to make many items for the building trade.

At the present time the use of plastics laminates as surfacing out of doors is limited by their weathering properties. The colours may fade, and they lose their gloss fairly quickly. It has been reported that most of the surfaces of laminates with paper and fabric bases which have been tested become matt in six months ; in this case repainting or resurfacing would be required. The limited evidence suggests that the strength of paper based laminates may suffer from weathering, although the strength of fabric

Modern Plastics, September, 1944.

based laminates was unimpaired after fourteen months. Their weathering makes them unsuitable for domestic outdoor use, but they have been adopted in other cases where replacement costs are of less importance.

A new group of laminates of outstanding properties has recently been developed in America*. These are the *fiberglas laminates* in which glass and plastics are combined. The glass is drawn into very fine fibres which have a tensile strength very similar to that in a high grade steel (i.e. 60–70 tons per sq. in.,) and a very high compressive strength. The fibres are made into fabric which is used to reinforce the plastics laminate. Each of the fibres is supported and lubricated by the plastics resin and if the laminate is heavily stressed, each fibre can extend and take up its share of the load, so that no undesirable stress concentrations occur. Should one fibre break, the strength of the remaining fibres is unimpaired so that cracks do not propagate. The fibres confer the strength of glass to the laminate without the brittleness which glass has in its massive form. The tensile and compressive strength of the laminate is very high, it has high impact strength, and is not "notch sensitive." It is light and shock proof, hard, and resists scratching and marring ; it exhibits neither cold flow nor fatigue effects, and so has potentialities as a remarkable structural material. Because of its resistance to weathering it has been suggested for use in outdoor furniture. Its water absorption is small and it has excellent dimensional stability.

Flat sheets can be drawn into shapes or they can be built up over forms. At present they are being used experimentally in aeroplanes as a structural material, and now after the war there is sure to be wide use of the material. It seems that many architectural items could be moulded inexpensively by using the techniques developed by the aeroplane industry, since the material lends itself to the low pressure moulding technique in which the expensive moulds necessary for the high pressure technique are avoided. The moulds may be of wood, plaster of Paris, concrete, etc., and the pressure required may be as low as 15 pounds per square inch. The temperature of curing is low (between about 120° and 220°F.) so that the pressure may be applied by inflating a rubber bag with air or steam. In another method the pressure is supplied by the atmosphere and the air is withdrawn from between the mould and a rubber blanket which is sealed to the mould at the edges.

In this way large assemblies can be designed as units and moulded at fairly low cost with rounded contours and corners and with smooth curves. A description has been given* of a prefabricated bathroom-cum-kitchen unit which takes advantage of the properties of this material. The unit embraces a bathtub which occupies a central position with a washstand,

**Industrial and Engineering Chemistry*, 1940, p. 1568.
Plastics Catalogue, 1944, p. 770. American Plastics Catalogue Corporation.
British Plastics, July, 1944, p. 440 ; October, 1944, p. 293.
**Modern Plastics*, October, 1944, p. 118.

refrigerator, kitchen sink, stove and W.C. grouped around three sides of it. The dividing wall is integral and separates the kitchen and bathroom items; it extends to the ceiling and runs round three sides of the bath forming a shower recess in which tiles are not necessary. In the kitchen a continuous working surface is provided for the housewife at table height, whilst above and below every cubic inch of space not taken up by the sink, etc. is used for storage. The design of the unit also incorporates aeroplane-type cantilever beams which carry the structure of the house.

After six years of war it is difficult to assess the future costs of production, but there are indications that for the mass production housing programme, plastics sheets may not compare favourably with many other building materials. Nevertheless, for the slightly better class of house there seems no doubt that such plastics will be used extensively.

ADHESIVES

Glueing is an old and well established method of bonding, and the joints formed in this way are strong and easily made. Until recently the adhesives used were based on products of animal and vegetable origin such as animal glue, casein, blood albumen, dextrin etc. Whilst some of these are cheap, their durability leaves much to be desired and, in particular, they show poor resistance to water and to mould and fungus growth. In recent years adhesives have been produced from plastics products. The most important of these are the *urea-formaldehyde* and *phenol-formaldehyde* adhesives; thermoplastics glues also are used for special purposes such as bonding glass sheets in safety glass. Phenol-formaldehyde and urea-formaldehyde adhesives give stronger joints than the conventional adhesives, are far more resistant to moisture and completely resistant to fungi. In fact, if exposed to weathering, the phenol-formaldehyde bond will outlast the wood. The urea-formaldehyde bonds are not quite as resistant to moisture as those using phenol-formaldehyde and, for use in extreme conditions, they may be fortified by including various percentages of *melamine-formaldehyde* resins, since these have better water resistance and durability. Phenol-formaldehyde adhesives are available in the form of solid powders, liquids and as a film of impregnated paper, whilst the urea-formaldehyde adhesives are mainly available in the liquid and solid powder forms. When supplied in the solid powder form, the hardener is already blended and the powder is mixed with water prior to use. When supplied in liquid form the resin and hardener are in separate containers and are either mixed before use or applied separately to the joints. Separately, they will keep for several months in a cool place, if contamination by acids, alkalies, etc. is avoided. The hot pressed adhesives give more durable bonds than the cold-set, and extenders such as wheat and rye-flour may be used to dilute the resin and still produce bonds which are

water resistant. The resin glue with a finely divided filler is more easily spread and does not penetrate the wood of the joint so much. The use of one part of resin to two parts of flour reduces the cost below that of the casein or the better grades of animal glue, and it is certain that the use of this type of adhesive for interior use and furniture manufacture will be considerably increased. For hot pressing a pressure of about 30 pounds per square inch and a temperature of about 200°F. are required. It is now recognised that even for "cold-setting" adhesives, some heating is an advantage and the term usually refers to glues which set in the range 100 to 200°F. The use of extenders is not recommended with cold-setting urea-formaldehyde adhesives since the bonds formed at the lower temperature, while durable, are inferior to those made by hot pressing. Moderate pressure is still required to bring the glued surfaces into contact and form good joints. The first of these urea-formaldehyde adhesives only gave strong joints if the gap in the joint was very small, that is, less than ·005-in. Recently, however, glues capable of bridging fairly large gaps, up to ·02-in., have been formulated.

The resin adhesives find their widest application in the glueing of wood, and in this respect they have undergone rigorous testing in the Mosquito aeroplane which is, apart from the engines, almost entirely of wood bonded with such resins. Nevertheless, the use of adhesives has been extended to the bonding of many other materials. Recent developments have been reported in adhesives for metals and light alloys. A method has been described for bonding certain metals together with a strength exceeding that of rivetting and of giving strong joints between metal and wood. The resin is mildly thermoplastic and the joints used lose strength at temperatures above 212°C. In fact, practically any pair of solids may be bonded together, wood to metal, metal to metal, rubber to metal, rubber to rubber, plastics to metal, plastics to plastics, etc. Thin veneers of decorative woods or plastics, rubber, leather, etc. may be simply glued to metal to give a fireproof sheet suitable as panelling for doors, metal columns and pillars. In this way there is wide choice of many finishes, colours, patterns and surfacing materials combined with the properties of the metal, and such combination sheets can be bent and formed without damaging the bond. In another application thin veneers of wood are bonded to a cloth, paper, or sometimes rubber backing, and these sheets may then be applied like wallpaper to walls, pillars, doors, ceilings, etc. Such an adhesive is easily applied by either brushing, spraying, or spreading, and one is reported which dries rapidly in 2 to 5 minutes and which is set after 24 hours at ordinary temperatures.

Rubber may be bonded to metal, wood, plastics and ceramics by suitable processes. Rubber mounting units may be made and used to support lift machinery, thereby reducing both vibration and noise transmission. Small rubber mountings are available for carrying units operating hot

water valves, and these assist in reducing noise along hot water pipes. Rubber mountings for flexibly supporting floors have been used with success.

RESIN-BONDED PLYWOOD

By far the largest proportion of synthetic adhesives is used in plywood manufacture*. Plywood has been used for years in the building trade, but its use was limited by the natural glues which formed the bonds. The association with plastics has produced a material of remarkable strength, beauty and durability, and the bonds formed by these adhesives are stronger than the wood itself. In particular, the water-proof properties of the resin bonds have enabled plywood to be used for such exterior applications as the outside sheathing of houses, and for use in contact with hot and cold water. *Phenol-formaldehyde* adhesive bonds will withstand prolonged soaking, hours of boiling, and repeated wetting and drying. Although the bonds withstand weathering, the outer surfaces of the outer plies develop " face checking " after about six months' exposure† unless protected by paint or some other treatment. A possible mode of treatment for the future is resin impregnation or the incorporation of a resin impregnated paper sheet on to the surface. The fact that the grains of the veneers run at right angles to each other means that the plywood gets the benefit of the grain strength in all directions and that the dimensional stability is very much superior to that of ordinary wood. The swelling and shrinking are negligible, being about one-tenth that of the separate plies in the cross-fibre direction. Plywood is proof against tearing and splitting and resists warping and buckling. The lightness, strength and rigidity can give plywood constructions twenty times the stiffness per unit weight of duralumin ; this quality has made the Mosquito the most versatile and formidable aircraft in service today.

Plywood is available in large panels up to 4 ft. by 8 ft. and 7 ft. by 12 ft. and in thicknesses ranging from $\frac{1}{8}$ in. to 1 in. thick. The large size of the panels and the lightness means that it can be installed and erected with a considerable saving of labour. This saving will often offset the higher initial cost of the plywood compared with timber. Large areas of unbroken surfaces are possible with a minimum number of joints and so a considerable improvement in weather resistance and draught exclusion is possible if plywood is used for wall and roof sheathing and for sub-flooring. Attics may be converted to use by boarding with plywood. Lath and plaster may be conveniently replaced by wall boards and ceilings of

***Plywood and its Uses.* U.S. Department of Commerce. Bureau of Foreign and Domestic Commerce, 1937.

Modern Plywood. Thomas D. Perry. Pitman. New York, 1943.

†A. J. Stamm and R. M. Seborg. *Industrial and Engineering Chemisty*, **31**, p. 897 1939.

plywood, and the large sheets available allow much smoother and more level subflooring on which to lay linoleum or other floor coverings. Glueing the plywood to the joists will completely eliminate squeaking floors.

The use of resin-bonded plywood is particularly appropriate for internal and external doors. Any tendency to swell, warp or twist, which the different humidities on each side may cause in a timber door unless carefully designed, is minimised. Flush doors have no ledges on which dirt and germs can collect. They are otherwise hygienic and the resin bonds are repellent to micro-organisms. The doors should be braced or filled with light materials such as an expanded plastic, otherwise they are liable to be resonant. Resin-bonded plywood has a much higher fire resistance than glued plywood, but the fire resistance of a door can be improved still further by incorporating asbestos or metal sheets. Phenol-formaldehyde bonded plywood is especially suitable for use in bathrooms, kitchens, and laundries, where the humidity is high. The outside surfaces of the plies should be protected, of course, to prevent checking. Resin-bonded plywood is a useful material for partitions, shelving, draining boards, etc. After steaming it can be bent to curves of large and small radii, and the architect can incorporate gracefully curved surfaces in his design and utilise this property to advantage in such applications as cantilever shelves and built-in furniture. It may be used for concrete forms; smooth curved surfaces are possible, which require very little finishing.

Plywood, through its ability to hold nails securely, contributes added rigidity to the structure when used as cladding. If instead of nails, resin adhesives are employed to attach the sheets, the bracing effect adds even more strength to the structure. The glue joint is continuous and so wind stresses are distributed through the joists and frame members to the glued plywood sheets of the walls, roof, floor and ceiling, which are an integral part of the load bearing structure. In this way strength and rigidity are obtained with far less wood than would be required by traditional building methods. The adhesives used in the assembly are cold setting, and the pressure may be applied by clamps, bolts, nails etc. Although the adhesive may take several days to set completely, the pressure may be released after a few hours.

In America, especially, resin-bonded plywood has been used extensively on a rapidly growing scale for the manufacture of prefabricated houses and housing units, in order to take advantage of the fact that it is cheaper and quicker to make large housing units in a factory and to assemble these units on the building site. In 1934 the U.S. Forest Products Laboratory designed and built such a house which was built up from a panel unit. Each panel unit consists of two plywood sheets glued to either side of an inner structural framework, and is virtually a box girder. Vertical mullions connect the wall units and the lateral edges of the floor

and roof panels are grooved and united by a spline. After eight years it is reported that this same house is still satisfactory* and that in 1941 forty-five companies in the U.S.A. were making prefabricated houses. These were being built at the rate of 2,000 houses per month and an average of 5,000 sq. ft. of plywood went into each house. The needs of the war production areas and of the U.S. armed forces have further increased the demand for this type of prefabrication.

An interesting British design on similar lines has been described†; this can be erected in 200 man-hours, of which 50 per cent are unskilled. The walls have an inner and outer skin of ⅛-in. plywood. The panels are joined together in the factory with synthetic adhesives to form larger sections such as whole walls. A 1-ft. section curved in a press is used to form the angles between the walls and floor. An expanded plastic or other light bulky material is contained between the inner and outer skin of the walls so that the overall thickness is 1⅝ in.; this is equivalent in heat insulation to an 11-in. hollow brick construction. Stressed skin structure makes sound insulation a very difficult problem, but this is partially overcome by the use of cupboards as baffles between rooms and by attention to other details.

During the war there has been wide experience of the techniques of using resin-bonded veneers of wood, and building houses of plywood would allow labour which has been employed in this way in the war effort to be retained for building after the war. Under the impulse of war, new techniques have been stimulated by the association of resin-bonded wood with aircraft manufacture. This has been especially the case with the development of cold setting adhesives and of the low pressure methods of moulding wood veneers. The rubber bag method has already been described and to a rapidly growing extent it has been used to mould large, complex, doubly curved shapes such as airplane fuselages, wings and nacelles. Sections as long as 84 ft. have been successfully produced for the construction of torpedo boats. Baths, sinks, tanks, furniture, and even staircases and entire rooms could be made by the same method, and it is reasonable to expect that in the near future many items such as vacuum cleaner housings which are at present made from formed steel sheeting, will be made from moulded laminated wood. The moulding of wood veneers around a light wooden core gives a member of great stiffness and lightness; this technique, which has been used with such success in the Mosquito, will find many applications in the manufacture of furniture.

A recent development which promises to improve and simplify pressing and moulding operations is the use of radio-frequency electrostatic heating. In this method the heat is not conducted from layer to layer as it would be if heated platens were used, but high frequency electrical energy generates

*F. J. Champion. *British Plastics*, December, 1944.
†The Jicwood House, see pp. 229-232.

the heat in situ within the wood and the resin. This technique is specially useful for bonding many veneers into a thick sheet and reduces curing times, pressures, and internal strains. A pair of electrodes may be mounted on a handle and used like a soldering iron; they may be used like an "electric sewing machine" for bonding along a line, or they may be mounted in the form of a gun which heats the adhesive locally and cures it in a few seconds. Nails, bolts, clamps and so on may be dispensed with during assembly, and the components held in position by "spot-welding" with these instruments.

Plywood tubing has been manufactured in diameters ranging from one inch to two feet. It has considerable strength due to the rigidity of the tube and to the grains of alternating plies being crosswise. Supporting pillars, rails and cornices are possible applications, and may be given a handsome finish by using an exotic wood veneer or a sheet of decorated and coloured plastics as the outside ply. Other posts and pillars may be concealed within split tubes. Compact telescopic wireless masts, clothes props and so on are possible applications.

Plywood has the grain of the alternate veneers at right angles to each other and the strength of the grain appears in all directions. If the veneers are glued together with the grains all parallel, the material has maximum strength and greatest stiffness along the grain. It is then usually referred to as laminated wood. Unlike natural timber which is limited in size and shape and has flaws in it, the plies may be selected, scarf-joined to any length and bent to any desired curvature. The plies are then glued together, care being taken to stagger the joints. Curved wooden members of this type have been developed since 1900, and with the advent of plastics adhesives attention has been attracted to the many structural possibilities which they offer, especially in conjunction with stressed coverings of plywood. Prefabricated aircraft hangars have been built, using laminated wood arches to which plywood is glued. Wooden arches, girders and trusses are easily shaped to have their maximum strength and stiffness where the stresses are high, and they can be curved to carry the loads. Glueing the veneers together allows each veneer to absorb its share of the stresses and there are no stress concentrations, as there would be if nails or bolts were used. The curving of the laminates to shape does introduce large stresses but some preliminary tests* have shown that even when they are bent as sharply as they can be without breaking the individual laminates, the glued member has about 75 per cent as great strength as a similar assembly glued together without bending. When the curvature is moderate there is very little reduction in strength.

The arches range from small gothic type arches which are suitable for use in small churches and are proof against death watch beetle, to large ellipsoidal types with a span of 150 ft.; the latter have been used in

*_Wood Handbook_, U.S. Department of Agriculture, p. 168.

industrial and public assembly buildings. Whilst the diversion of metals for war purposes has facilitated the utilisation of laminated wood arches, nevertheless their merit as roof supports is such that their use will grow rapidly. The increased dimensional stability conferred on wood by laminating it will recommend laminated wood for uses externally and in places such as kitchens, laundries and bathrooms, where the humidity is high.

If, instead of just coating the plies with adhesive, they are impregnated with about 30 per cent of resin before glueing together, their resistance to swelling and shrinking is considerably increased. The hardness, compressive strength, and resistance to checking are also improved. Such impregnated wood is bonded at normal plywood pressures of up to 200 pounds per square inch, and the specific gravity is only a little greater than that of wood. If the bonding pressure is increased to 1,000 or 1,500 pounds per square inch the veneers are compressed and densified. The product then has a specific gravity of 1·3 to 1·4. The specific gravity may be made to vary continuously from one end to the other by inserting short plies at places where the specific gravity is required to be high. The mechanical strength of the material runs parallel with the specific gravity and these properties may be controlled to suit the function. A brilliant example of this is its use in airscrews. The blades have high specific gravity at the hub where strength is required and low specific gravity at the tip to reduce centrifugal force. High density, laminated wood will find extensive use in transport, but the present cost will restrict its use in construction except for applications where hardness, strength and lightness are specially required. Lifts, escalators, and doors are possibilities, and light weight household tools and utensils such as coal scuttles will be appreciated by the housewife.

FLOORING AND ROOFING

The application of plastics materials to floor covering is only in the first stages. It is certain that the linoleum industry, which has many similarities to, and points of contact with, the plastics industry will extend considerably the use of plastics in floor-covering. Sheets of *polyvinyl chloride* have been used in the U.S.A. and in Germany and floor coverings of this material in a range of colours are now available in this country. It is a tough, flexible, rubber-like material, warm to the touch, completely waterproof, a good heat insulator, and non-slip. The non-slip properties are further improved by embossing a fine pattern on the surface. Such properties as these suggest its use in halls, corridors, lifts, kitchens and bathrooms. Compared with linoleum its initial cost is a little higher, but its excellent wearing properties reduce replacement costs. Another product is made of an abrasive material

such as ground garnets, bonded with a suitable plastics ; this is specially suitable for non-slip floors. It may be applied either with a trowel or by spraying, and by the choice of a suitable bonding material metals can be firmly coated with it. A typical product has been described as quick-drying and resistant to cold, heat and fire, and to oil, grease and soap ; this may find application in special uses such as the surfaces of garage floors.

Instead of being used as a large sheet for flooring, polyvinyl chloride has been used in the form of small tiles which are coloured and wear resistant. Floor tiles have been manufactured from *coumarone-indene* resins, two substances which are derived from coal tar and which are used in paints and varnishes and as binders in linoleum. These tiles are light in colour and resistant to water and alkalis. For such purposes it is natural that sand and siliceous materials should be bonded with synthetic adhesives to make tiles, the strength characteristics of which are superior to those of a concrete tile, and they are slightly lighter. They are warm, smooth and colourable. The cost at which they could be produced is similar to that of concrete tiles. Sand bonded with a synthetic resin has been used as a cement for jointless flooring and for window surrounds. The plaster-like material is applied by means of a trowel and after a few hours sets hard and smooth. Cellulose plastics have been used as terrazzo floor divider strips and for linoleum trim.

Coumarone-indene plastics have been used for roofing purposes and have been considered satisfactory. For other materials weather resistance must be considered if they are to be used out of doors.

HEAT INSULATION

Far too little attention has been paid to the heat losses through the walls, windows and roofs of buildings, with the result that heat is wasted in keeping the buildings warm in winter, and they are difficult to keep cool in summer. A balance has to be struck between the initial cost of building a house with good heat insulation and the cost of heating a poorly insulated one. The balance may also have to take into account the convenience of maintaining the heating—a stove which requires constant attention is a nuisance. Again, freedom from condensation on walls, windows and other surfaces is desirable, but the justification in terms of expense is difficult to evaluate.

The heat losses through a material are best discussed by a comparison of their thermal conductivities. The higher the magnitude of this property is the greater the heat loss. It will be seen from the table overleaf that the materials used in building vary considerably in their heat insulating properties :

Material	Thermal Conductivity
Granite	13–28*
Concrete	6–9
Glass	5–6
Building brick	3–6
Phenol formaldehyde (paper lam.)	1·4–2·2
⅜-in. resin bonded plywood	0·9
Wood	0·3–1·1
Solid polystyrene	0·5
Beaver board	0·34–0·54
Celotex	0·33
Expanded thermosetting plastics	0·28
Cork board	0·25

The degree of heat insulation of walls which is desirable for the climate of this country has been mentioned† as 0·15 to 0·20 B.ThU. per hour per square foot per degree Fahrenheit. The usual 11-in. brick cavity wall has a conductivity of about 0·30, which is inferior to the desired standard. Naturally, smaller thicknesses of brick are required to attain the standard if the wall is panelled with materials such as wood or the various plastics materials, or if the cavity is filled with a thermal insulator.

Plastics are used as bonding agents in making glass and rock wool bats, cork compositions, etc. Various plastics products are manufactured which, whilst having as good heat insulating properties as cork, are much lighter and are completely rot proof and more vermin resistant. One such plastics product used in refrigerators has a number of corrugated sheets of black cellulose acetate bonded together, so that small air spaces are enclosed between the corrugations. These sheets have about one-tenth the weight of the same volume of cork and they have been used for roof insulation, where their lightness is very valuable. Sponge-like cellular materials are made by blowing compressed air into, or by generating gas bubbles in, a molten thermoplastic resin and cooling. Similar materials have been made by generating gas in thermosetting plastics or by condensing in emulsion form; foam-like materials are produced which have lower heat conductivities than rock wool, glass wool, or cork. These materials have good mechanical properties, considering their nature; the compressive strength, for instance, is about 100 pounds per square inch, they are fire-resistant, odourless, and sheets can be bonded to metal or plywood. A novel material of this type expands in situ. After mixing the ingredients the product resembles molasses in appearance; it begins to foam and expands to thirty times its own volume in five minutes. Curing takes place without further application of heat or other attention. This substance will fill by expansion any space into which it is put; it would seem to be very suitable for filling irregularly-shaped cavities in which it would be inconvenient to put regular sections of insulating material.

Materials of this nature possess valuable sound insulating properties

*B.Th.U.'s per hr. per sq. ft. per in. thickness per 1°F. Temp. difference.
†M.o.W. Post War Building Studies No. 1—*House Construction*.

and a process has been patented for preparing an elastic porous material, based on a rubbery plastics which deadens sound, and can be applied as a layer to metal panels and the like.

The transparent plastics have very much better thermal insulating properties than glass ; this is important as a considerable proportion of the heat losses from a room are through the windows. The transparent plastics can be blown into flat, hollow panes which have excellent heat insulating properties, but these will only be available for special purposes such as windows in refrigerators, and so on. The adaptability of plastics to ingenious solutions of such problems is well illustrated in the design of a heat insulating panel. A sheet of aluminium is inserted between two sheets of plywood or plastics laminate so that there are air spaces on each side of the aluminium. The aluminium reflects a good deal of the heat and the plastics sheets and air spaces have a high heat insulation. Panels of this type have been found practical for tropical use.

PLUMBING

This war has seen the partial replacement of metal pipes by plastics in industry. These pipes have been made of the thermoplastics, *polyvinyl chloride* and *vinylidene* polymers, of thermosetting *phenol-formaldehyde* plastics, and of resin-bonded plywood. They have been used for conveying a large variety of corrosive chemicals and oils. Joining of these tubes can be carried out in several ways. The ends of the tube can be flanged so that the sections can be bolted together, they can be cemented, they can be threaded with the usual pipe dies and in the case of thermoplastics they can be welded. For welding, it is sufficient in some instances to warm the ends of the tubes and then force these ends together. In other cases the ends are placed together and the joint made with a " flame " of hot air, a process reminiscent of welding metal. The success of plastics tubing in industry naturally suggests the use of such pipes in the home. Their advantages over metal are that they are more resistant to corrosion, both chemical and electrolytic, and lighter in weight. The resistance to corrosion eliminates the danger of metallic poisoning. Of course, the use of these plastics in plumbing would mean a new technique, but this would not be difficult to acquire. It is reported that many technicians find plastics tubing quicker and easier to handle than copper tubing. With thermoplastic tubing, more rigid fixing might be required, owing to possible cold flow. Resistance to freezing would be better than that of metal tubing, but it is not known whether the probability of rupture would be less. It seems reasonable to say that, for mild frosts and short, but hard frosts, plastics tubing would be superior to metal, by virtue of its low thermal conductivity. For long, hard frosts, freezing would probably occur both

with metal and plastics, with consequent rupture of the pipes. For cold water pipes a good case can be made for plastics, as also for water and gas pipes in contact with soil, since the danger of electrolytic corrosion is eliminated. Even here however, plastics and metal have been combined and metal pipes with a thick protective coating of plastics have been produced. The value of using plastics pipes for hot water supplies is debatable at the moment, but the situation is promising, since laminated phenolic plastics tubing has been used for conveying hot brine. Reports from the U.S.A. claim success with *vinylidene* plastic tubing and shower heads for conveying hot and even boiling water ; many housing units in defence areas are installed with this type of piping and fitting, but under more normal conditions it would probably be too expensive for domestic use. It is understood that a few extruded phenolic waste pipes are in experimental use.

A number of other fittings such as plastics toilet tanks, flush valves, cistern floats and lavatory seats have been previously mentioned. To these fittings should be added sink stoppers of *urea-formaldehyde* mouldings, which have been reported to stand up well to use, towel rails and faucet handles with a metal insert. Of great interest is the use of plastics for wash-basins. The difficulty with such objects is not their water resistance but whether the surface will stand up to the abrasion of normal cleaning operations. This difficulty does not appear insurmountable, since wash basins for marine use have been made of moulded polyvinyl chloride and also of urea bonded plywood.

Water softening, while essential for many industrial processes, is not yet usual in British homes. The materials used for water softening until recently were either modified natural products or inorganic materials. About ten years ago* it was discovered in this country that certain synthetic resins had the power of removing salts from solution in water. Since then, much work has been done on these and similar compounds, and they have found extensive use in industry ; however, the authors do not know whether they have been used for domestic purposes. All classes of water softening materials lose their ability to soften water after they have absorbed a certain amount of material, but treatment with certain solutions, which vary according to the type of water softener, will restore the activity. Thus, the water softening material goes through a cycle, in the first part of which it fulfils its function, and after a certain time must be revived. The synthetic resins, when compared with other water softening materials, have been found to be more durable under rough treatment and not to lose their efficiency after a large number of cycles, as do the other materials.

*B. A. Adams and E. L. Holmes, *Journal of the Society of Chemical Industry*, 54, p. 1, 1935.

SOIL STABILISATION AND CEMENT CONDITIONING

Under some conditions, it is necessary to stabilise the soil on a site so that it is sufficiently compacted to bear the weight of a house. The soil is pulverised and made homogeneous, water being added to it if too dry. Liquid or solid stabilisers and cement are then added and after thorough mixing the soil is compacted. The purpose of these stabilisers, which can be synthetic resins, is to prevent the absorption of further water. Recently, a low cost, soil-stabilising resin has been described which has very suitable waterproofing properties. It is reported that a road bed, which had been treated with this resin, was exposed to torrential rain for fourteen hours, but that no mud was formed. Another unusual application for synthetic resins, described in 1944, is in the improvement of the weathering properties of cement. Concrete beams made with cement containing a small amount of this resin. were exposed to ice-cold winds and sea-water. Various concretes were tested under these conditions and all but the resin-treated concrete deteriorated rapidly. It is further claimed that this resin permits faster and easier spreading and results in smoother surface texture.

PAINTS AND COATINGS

The field of paints and coatings is one in which plastics have proved superior to natural products and in which a large part of the output of the plastics industry is used. Apart from lacquers based on the semi-synthetic plastics *cellulose nitrate* and *cellulose acetate*, the introduction of plastics products into the paint industry began about fifteen years ago with a class of resins called *alkyd* or *glyptal resins*. Typical of these materials are those obtained by the chemical reaction between glycerine, certain fatty acids and phthalic anhydride, which is obtained from naphthalene. Their chief use so far has been in industrial applications such as the coatings for cars and refrigerators, often in combination with cellulose nitrate or acetate. In fact, it has been stated that by 1936 they had completely replaced other lacquers as coatings for refrigerators. These lacquers based on alkyd resins require stoving ; the normal practice has been to carry this out in special ovens, though recently two new processes have received attention. In one used to a considerable extent by the motor industry, the drying is carried out by infra-red radiation.

In the other method, a jet of hot gases is directed on to the surface by means of a hose. Since the apparatus is portable, large areas of painted surface can be dried in this way. These methods reduce the time of drying to a matter of minutes, are more controllable than air ovens, and a smooth, hard surface free from blemishes is obtained. The advantages of alkyd resins are that they are easy to apply, have a deep gloss and good colour retention, are resistant to weathering and ageing and the colour does

not deteriorate on baking. Heat resisting alkyds have been used for painting gas fires. This field is continually expanding and, for example, alkyd resins modified with soya bean oil have been recommended for non-yellowing interior paints. Alkyd resins have also been supplied as water emulsions and these are particularly useful for application to porous surfaces, where they give excellent resistance against weathering and abrasion.

A year or so before the war, paints based on *urea-formaldehyde* resins were put on the market. Alone, these resins give films which are rather brittle, and they are therefore softened or " plasticised " by the addition of an alkyd resin. These paints are generally stoved at 200–220°F. for about half an hour, and give very tough films with a fair gloss and good adhesion. Their heat resistance is good, but they do not stand up well to moisture and weathering. Recently paints based on *melamine-formaldehyde* resins plasticised with alkyd resins have been produced. These products can be stoved at lower temperatures (175–200°F.) than the urea-formaldehyde compositions and require less time for hardening. They produce harder films and resist discoloration and moisture better. By the use of certain hardeners, plastics paints of this type can be made air-drying.

A large range of resin paints based on *phenol-formaldehyde* is available. The salient feature of these paints is the extremely good protection which they offer to corrosion and weathering. These phenol-formaldehyde paint resins can be broadly divided into two classes ; in the first class the resins themselves form the coating and in the second they are used as a component of the paint and are termed oil-soluble. Paints of the first class are used as stoving finishes and produce films which are hard and have a high resistance to corrosion but are brittle. Paints both for decorative and for protective purposes are available in the second class. These possess excellent weather resistance, durability, and may have a gloss or dead flat finish as required. Floor varnishes and paints with excellent resistance to soap and cleaning materials are manufactured, as are emulsion paints for application to plaster walls and wall papers, in pastel shades and white. Emulsion paints have been produced which do not need a primer and can be used on a wide range of surfaces. These emulsion paints are odourless and are therefore very suitable for hospitals and other buildings which are in continuous occupation.

New synthetic resin paints with a diversity of properties are continually appearing. Two illustrations will emphasise this adaptability of the plastics industry. In one, a resin emulsion paint suitable for walls and ceilings, which is easily applied, dries in one hour, is available in white and eight pastel shades, and can be washed with soap and water, has been reported. In the other, a permanently flexible paint which contracts and stretches with temperature (–32°F. to 500°F.), and never dries hard, has been described. It is odourless and tasteless, can be applied to pitted surfaces

and resists moisture, corrosion and fungus. A possible use for this product may be as a protective coating in hot water cisterns.

SUPPLY

Although there are many possible applications of plastics to architecture, the magnitude of their contribution to the contemplated programme of post-war housing must be put into proper perspective. This contribution will be determined by the scale of plastics production, the demands of plastics for other purposes and competition from other materials. The present production figures of this country have been officially withheld, but an idea can be obtained from pre-war estimates and from figures for production in the U.S.A.

In the U.S.A., the total production of plastics during 1943 was 422,000 tons at an average price of 38 cents per pound*. This figure includes all plastics such as alkyd resins for paints, impregnating compounds, binders, plywood adhesives etc.; of this total about 100,000 tons was for moulding purposes. The annual production of all plastics materials in this country just prior to the war is estimated at about 30,000 tons. Expansion has taken place during the war—one factory has reported a twenty-fold increase in capacity, but this is exceptional—a fair guess would put the expansion at aboutthree-fold, so that present production would be about 90,000 tons per annum†.

In the first post-war year there will be a recession of output as the industry changes over from war production. A large proportion of the plastics will be in demand to make up deficiencies which have accumulated over six years, to repair, equip and repaint existing homes, transport, shipping and industry, and for export. It is reasonable to conjecture that only a small fraction of production will be available for new housing. If this fraction is put at 10 per cent the figure of 9,000 tons per annum is obtained. At the peak scale of rehousing of 750,000 new houses per annum, only about 30 pounds of plastics per house will thus be available. When it is remembered that part of this would be in the form of paint and resin-bonded plywood, it is clear that plastics will not contribute on any large scale.‡

There has been much discussion about the probability of competition between plastics and metals, particularly the light alloys. Moulded plastics compete with die cast, sand cast and machined metal; laminated plastics and plywood with formed and machined sheet metal; resin protective coatings with plating. Even so, as Scribner points out§, the fields

**British Plastics*, September, 1944, p. 397.

†This would correspond with the rate of expansion of the industry in the U.S.A. during a similar period.—*Modern Plastics*, November, 1944, p. 97.

‡Caress, *Chemistry and Industry*, July 31, 1943, p. 287.

§G. K. Scribner, *Metals and Alloys*, August, 1944, p. 336.

of application in which plastics and light alloys overlap and compete are relatively small. Their contrasting properties in regard to heat and electrical insulation, resistance to temperature and corrosion, mechanical strength, colour transparency etc., often mean that they are mutually exclusive. The figures for the production of plastics in the U.S.A. which have been given above, have to be compared with figures of 90,000,000 tons for steel, 1,400,000 tons for aluminium and about 300,000 tons for magnesium*. The recent expansion in the production of light metals has been for war purpose such as aircraft, explosives and incendiary bombs, which will not be required after the war. Light metals will therefore find that their market has been reduced and a new one will have to be created. On the other hand, plastics have such a large potential peace-time market that supply will fall short of demand and in the immediate post-war years there will probably be very little competition.

To meet this shortage there seems but little prospect of a spectacular increase in production in the immediate future. The thermosetting phenolic resins were the principal item in plastics production before the war and still are . In 1942 Chapman† considered that in this country the potential yields of natural and synthetic phenol were respectively about 20,000 and 25,000 tons annually, and even if all of this were made available for plastics only about 45,000 tons of resin would be produced, equivalent to about twice that amount of moulding powder. An increase in the scale of production of urea-formaldehyde resins is more hopeful, since all the raw materials are synthetic and the main consideration will be the price of coal and power. In the thermoplastics field the main burden is taken by the cellulose plastics—they constituted 60–65 per cent of U.S. production of thermoplastics in 1943‡. Since these are derived from cotton linters or pulped wood, the prospect of an increase in their supply would seem good. Calcium carbide is an important source of plastics and of many other chemical products ; prior to the war, there was no calcium carbide produced in England and it is doubtful if the present production will be available for plastics after the war§. The increased cost of coal will not favour the manufacture of carbide, but it may force industry to utilise coal and its by-products more efficiently than hitherto.

With this potential demand, attention is being paid on an increasing scale to other sources of plastics materials. Sea-weed is a source of alginates from which fibres and non-inflammable laminates can be obtained. Silicone resins have been derived from sand but their price at present is about 35 shillings a pound. There are available enormous tonnages of waste agricultural products ; for instance, there is an estimate that 100,000,000

*J. M. Weiss, *Chemical and Engineering News*, December 10, 1943.
†C. Chapman, *Chemistry and Industry*, December 12, 1942, p. 509.
‡R. H. Ball. Paper delivered to the Fall Meeting of the Society of the Plastics Industry, November 9, 1943.
§H. Levinstein, *Chemistry and Industry*, June 17, 1944, p. 226.

tons of agricultural material such as cotton seed hulls, wood, nut shells, etc. are wasted annually in the U.S.A. Chemists have already made considerable progress in the technique of converting such products to plastics* ; furfural is obtained from oat hulls and other farm wastes and is used in phenol-furfural resins. Coffee beans, soy beans, cashew nuts are all found to have possibilities as sources of plastics. In Canada the paper industry wastes about 500,000 tons of lignin as a by-product each year ; lignin can be considered as a sort of natural phenolic resin and efforts are being made to develop a process for utilising it as such†. Whilst it is desirable to have raw materials which are cheap and available, the cost of them is usually but a small part of the final cost of the product and unless the conversion is very simple or the final products have an intrinsic merit of their own they may not be able to compete with other plastics. Nevertheless, there exists a distinct possibility that before very long a cheap plastics material will become available in large quantities.

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The applications of plastics to various branches of industry are treated by a number of experts in these industries in *Plastics in Industry* by "Plastes" (Chapman and Hall, 2nd edition, London, 1940). Architects will find *Plastics for Production* by Paul I. Smith (Chapman and Hall, London, 1944) and the *Handbook of Engineering Plastics* by D. Warburton-Brown (George Newnes Ltd., London, 1943) particularly useful ; in these two books there is an extensive collection of data on the chemical, physical and mechanical properties of plastics. The applications of plastics to post-war building has been studied by a Committee convened by the British Plastics Federation. This Committee has issued a report which was published by His Majesty' Stationery Office in 1944. Recent years have seen a growing realisation of the importance of design in plastics products

*O. R. Sweeney, L. K. Arnold, W. D. Harris, *Modern Plastics*, December, 1941.
†R. V. V. Nichols, *Canadian Chemistry and Process Industries*, March, 1944.

and this subject is treated in *Plastics Industrial Design* by John Gloag (Allen and Unwin, London, 1945). The book also contains a useful summary of the principal plastics materials and their properties by Grace L. Fraser.

The principal journals which deal with the subject are *Modern Plastics* (Breskin Publishing Corporation, New York), *British Plastics and Moulded Products Trade* (Iliffe and Sons, London), *Plastics* (Temple Press, London) and *Plastics World* (Cleworth Publishing Company, New York, N.Y.).

The *Plastics Catalogue* (Breskin Publishing Corporation, New York) is issued annually and is a mine of information on the whole industry. The corresponding publication in this country is the *British Plastics Year Book* (Plastics Press Ltd., London).

In addition to these publications, firms in the industry supply detailed brochures, pamphlets, booklets, etc., which give details of the physical properties of their products and which deal with the actual and potential applications of these products.

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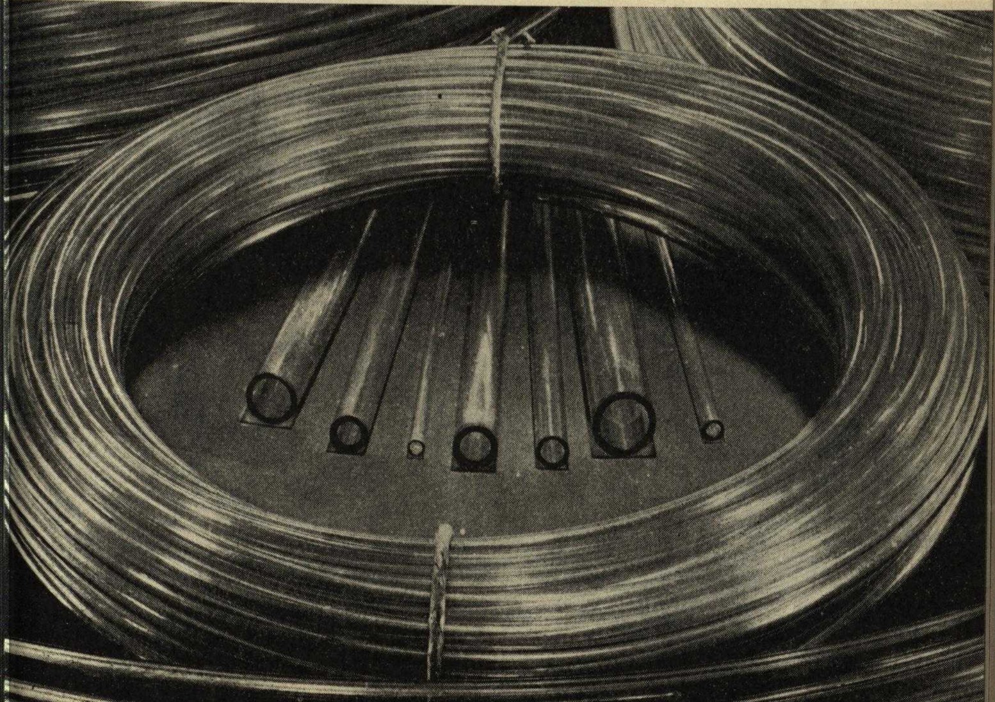
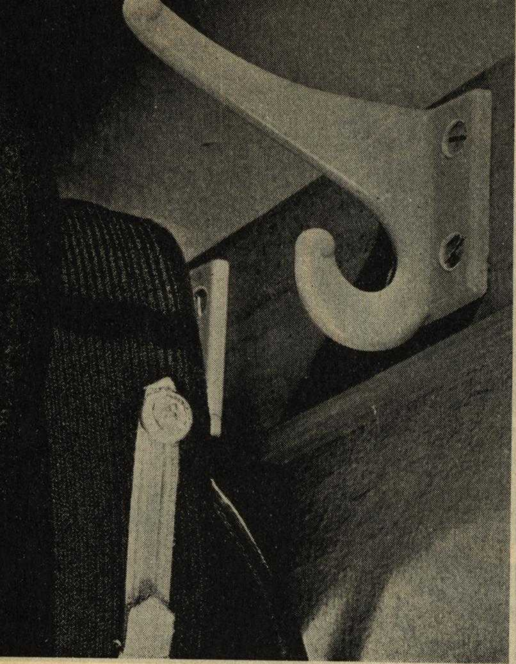
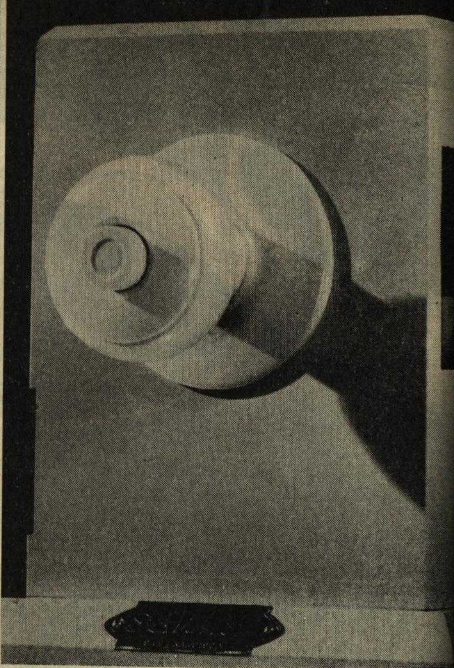
15. Welvic (polyvinyl chloride) in chip form, ready for despatch in drums.

16. Tenite (cellulose acetate-butyrate) tubing, extruded in continuous lengths, transparent and virtually unbreakable.

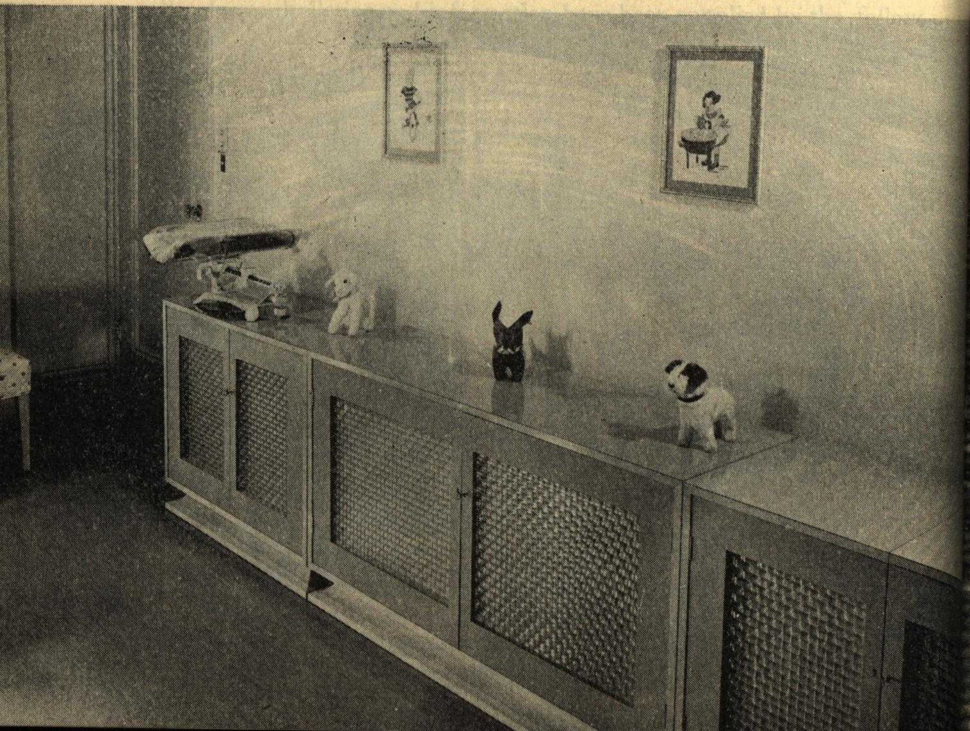


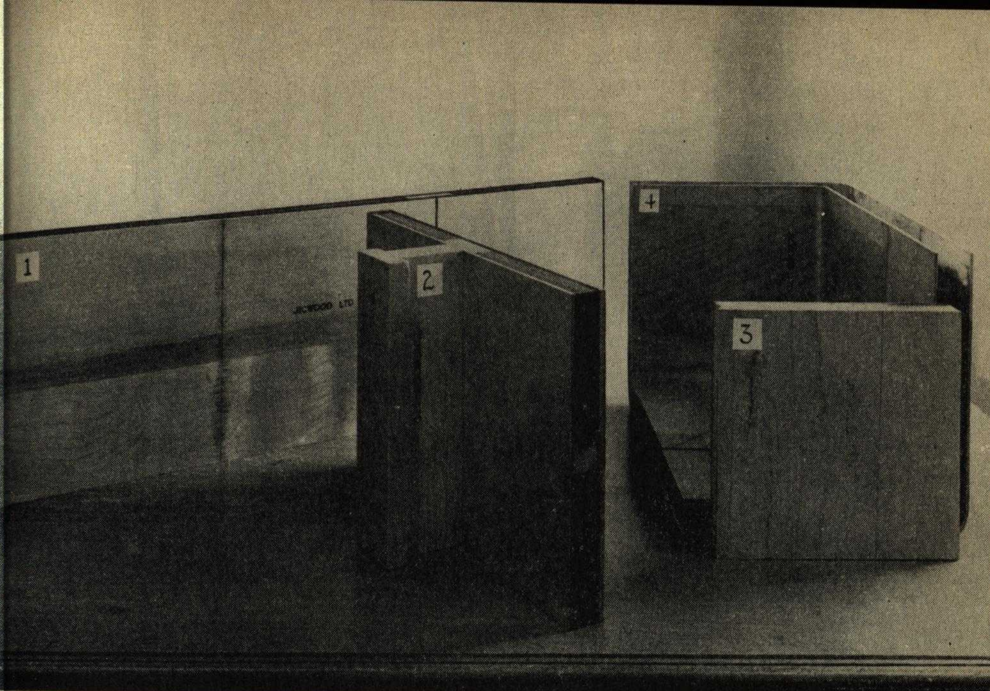




Three domestic uses of Tenite, formed by injection moulding in an unlimited range of colours.

17. Coat hook.
18. Door knob, with locking device.
19. Woven Tenite, used in cupboard door panels.

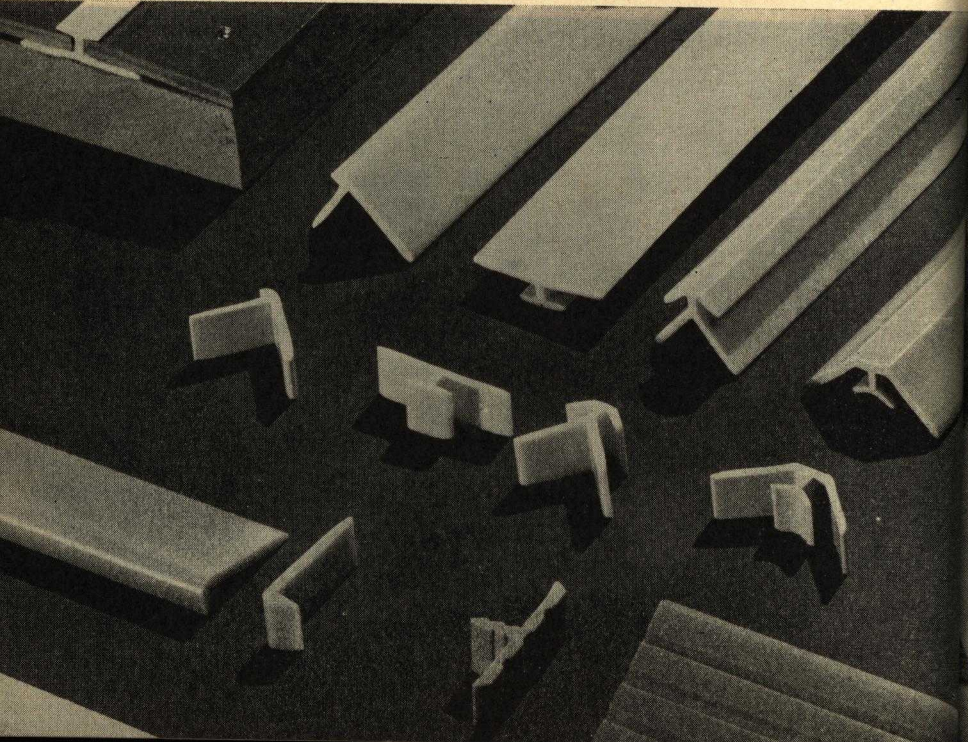


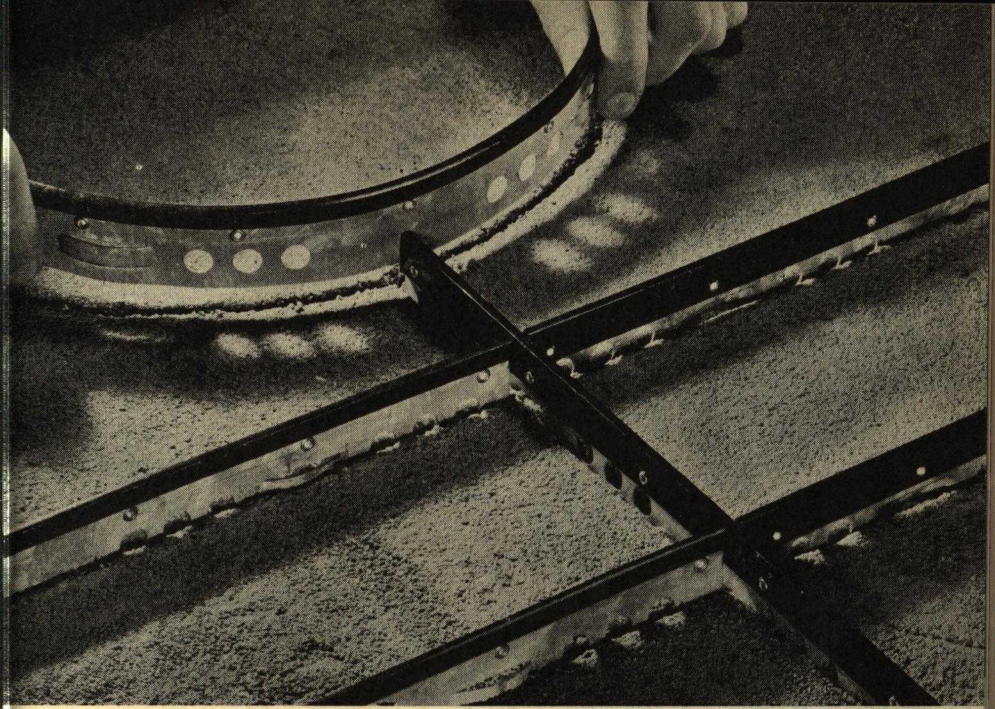


20. Four sample pieces of Jicwood plastic laminated board.
    1 and 3. Wall panels.
    2. Flooring (attached to wooden beams).
    4. Corner section shown moulded to shape.
    For an application of Jicwood, see pages 229–232.
21. A section of Hydulignum, showing grain produced by consolidating to 80lb. per sq. in.

22. Tenite cover strips are extruded to fit inside and outside corners and flat panels. The shape of these strips secures them in position without any further means of attachment.

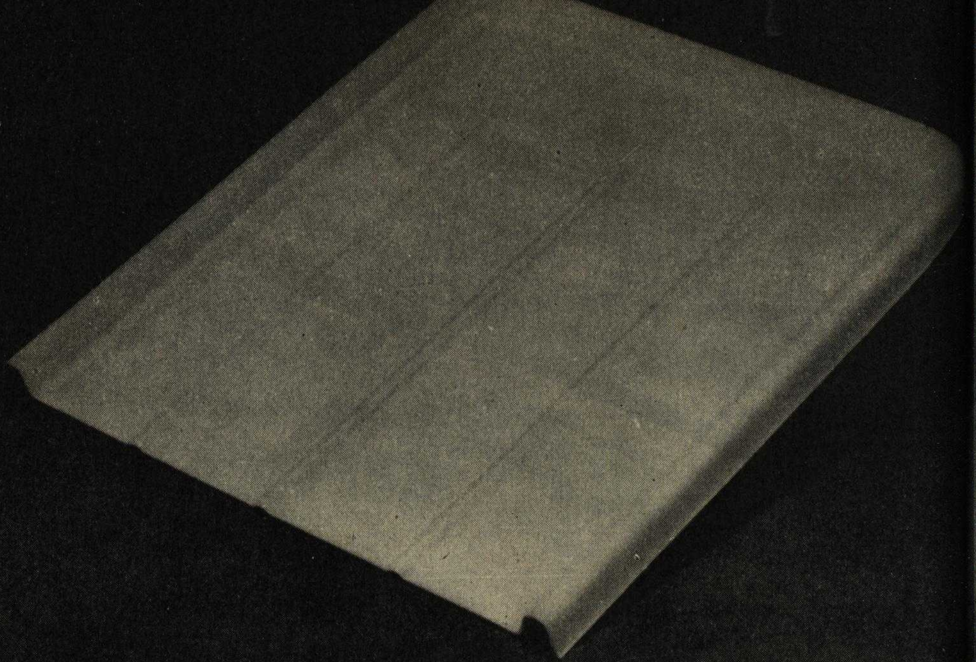
23. A selection of extruded plastics sections (Tenite). Compare these with the light alloy extruded sections (Figs. 3, 4).





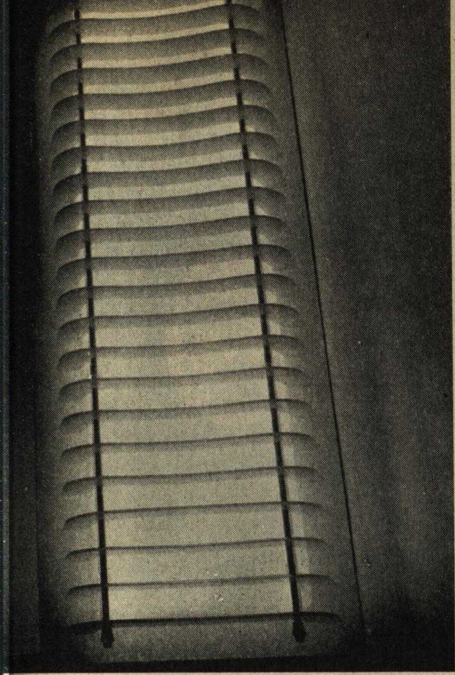
24. Plastic-faced strips used with terrazzo flooring.

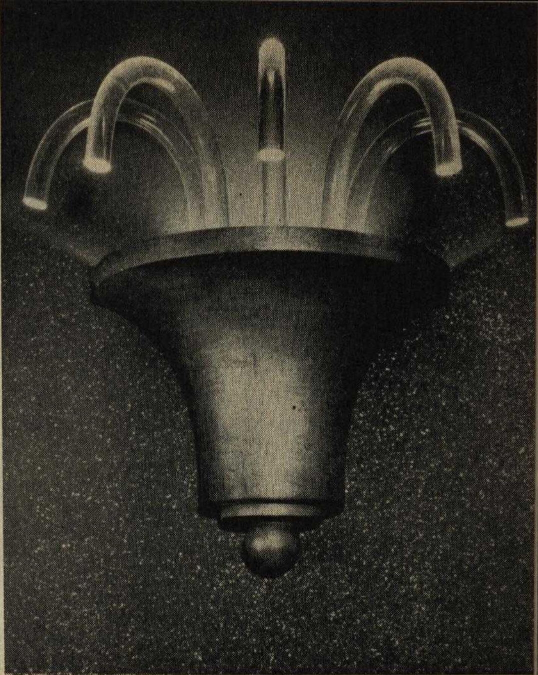
25. Plastic strips used to trim the edges and corners of a sink and draining]board.



26. Perspex (polymethylmethacrylate) draining board.

27. Perspex coloured hand basin.





Two uses of plastics in lighting fittings :

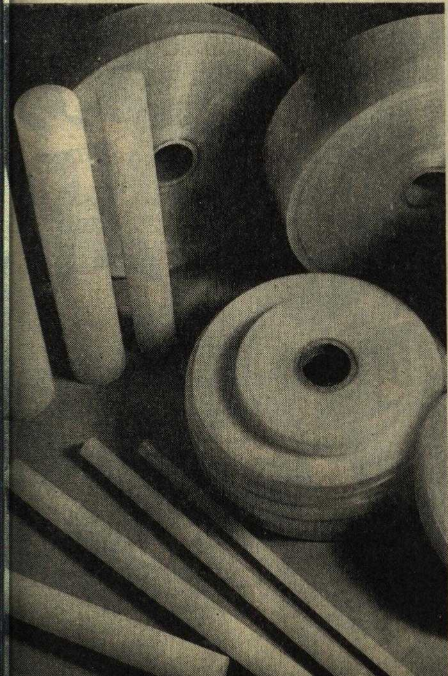
Ceiling fitting for use with fluorescent lighting, consisting of corrugated sheet Lumarith supported by glass rods.

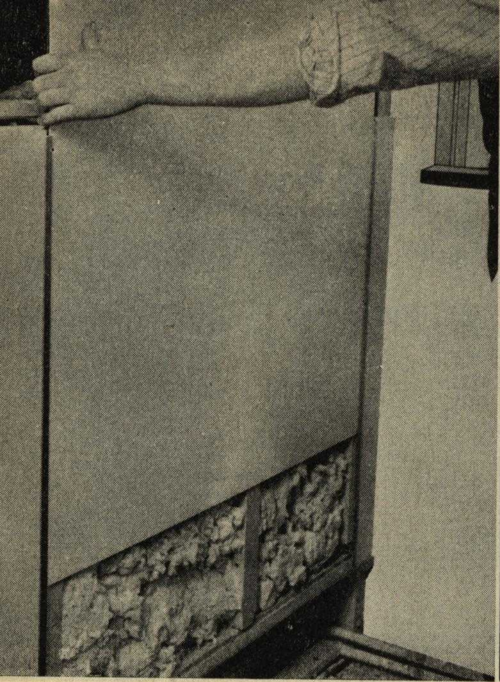
29. Wall fitting. The light is hidden in the base and is piped through the Plexiglas rods.

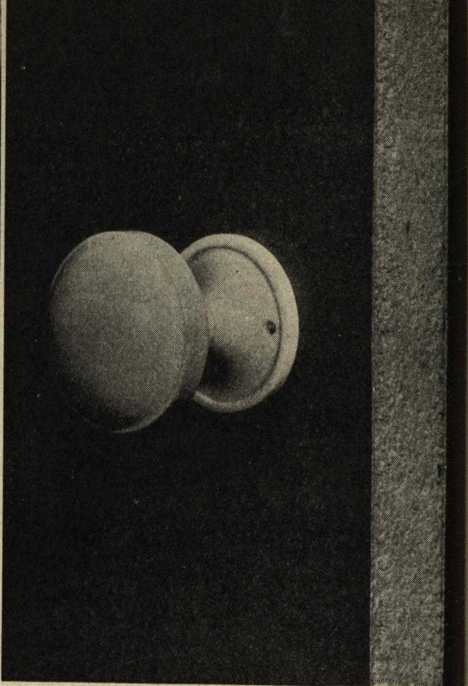
Two further applications of plastics :

Alkathene (polythene) in film and rod form.

31. Alkathene (polythene) and Welvic (polyvinyl chloride) insulated cables. The former is used for the core and the latter for sheathing.





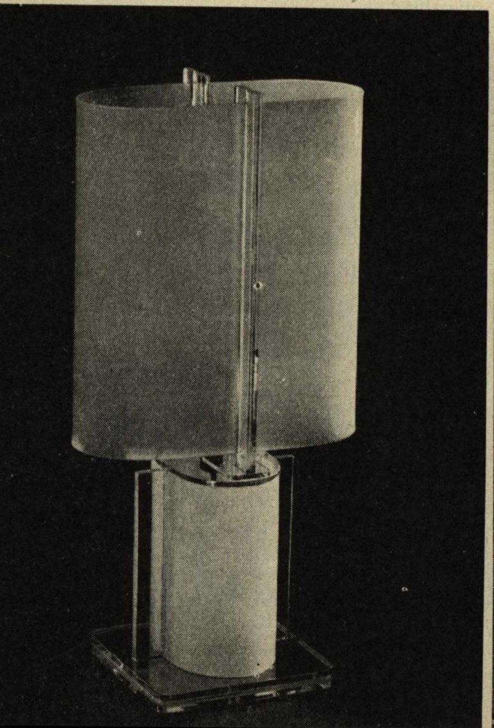


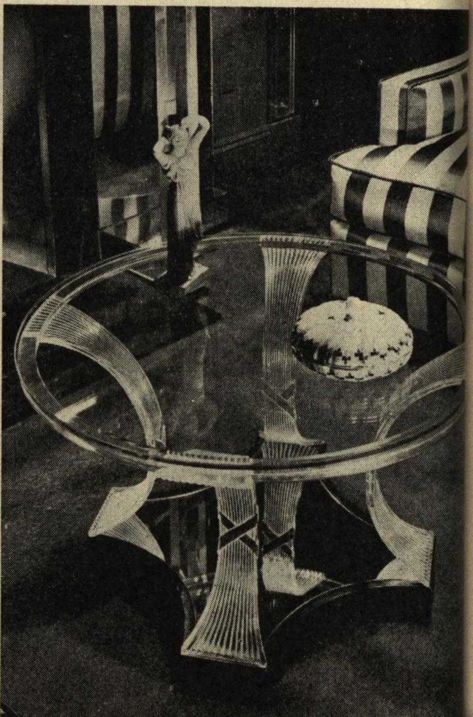
32. Bakelite panels being slid into position to provide a durable interior finish.

33. Section through a new type of door, comprising plastic core material faced with plastic-coated metal.

34. A decorative plastic table lamp.

35. Decorative use of $\frac{3}{4}''$ Plexiglas.





SECTION III

TIMBER AS A BUILDING MATERIAL

In contrast to the other materials described in this book, timber has been used in building throughout the ages. Its qualities automatically recommend it for such a use. Wood in some form is to be found in most parts of the world ; it is an extremely sympathetic material, is readily worked and is one of the few natural materials possessing tensile strength.

As a result, a very highly developed craftsmanship in woodworking has evolved. This is far removed from the laboratory techniques applied to plastics or metals. Until very recently there has been little attempt to codify the mechanical properties of woods, and the design of structural timber has been done by rule of thumb.

It was perhaps inevitable that sooner or later the technique of using wood should come more into line with that employed in the case of its modern rivals. This process of adaptation to modern methods has been greatly accelerated by the war, which found us desperately short of timber and which forced us to adopt every device which would help to eke out supplies.

The new need for economy is reflected throughout Mr. Lockyer's Paper and rightly so, for wood is likely to remain restricted in quantity for a long time to come.

The author describes three main ways in which we can reduce our reliance on imported softwoods. These are the increased use of Empire and home grown hardwoods, the more scientific design of structural timber, and the greater use of the short lengths and other by-products of the sawmill which have been treated as scrap in the more extravagant past. He stresses throughout that care in selection, seasoning and preservation of timber is amply repaid by results.

TIMBER AS A BUILDING MATERIAL

By FRANCIS LOCKYER, M.A. For. (Cantab.)

BEFORE dealing with the more modern applications of wood as a structural and decorative material it may be as well, in this country with its traditions of steel, brick and concrete, to review some of the processes through which the raw material has to pass. Although the use of wood is a subject about which one never ceases to learn, the principles which should govern its preparation for a specific purpose may always be applied, and if intelligently carried through will afford satisfaction. The three cardinal principles can be summed up in the words selection, seasoning and preservation.

SELECTION

The main carcassing timber of a building is usually of softwood ; thus the joists, floorboards, rafters and purlins are derived from coniferous trees such as Scots Pine and imported Baltic fir (known by the trade as Red Deal) or Norway Spruce (White Deal). These trade names may confuse because Memel, Archangel or Baltic fir is not truly fir but pine. Again Douglas fir, which is " a false hemlock," is called in the trade Oregon or British Columbian pine. However, the main significance here is to be found in the country or district of origin. Softwood from Archangel or the northern gulfs of the Baltic is of a more closely knit and regular texture than that from further south, or from that grown in this country. The reason is that the annual growth in the northern regions is less, the climate is more regular in its effect upon growth, and the timber is therefore more homogeneous. Such wood is admirable for joinery where a fine finish and nice precision is necessary. Again, Douglas fir grown in the mountainous districts of the Rockies is easier to work and finish than that grown in the coastal region where trees lay on girth and height more rapidly. Quick growth gives a very marked distinction between the summerwood, which is the dark tough part of the annual ring as seen in cross-section, and the springwood, which is the lighter-coloured and softer region. Furthermore, unless a tree is grown fairly closely with its neighbours the bole will be covered for too long with yearly thickening branches which make atrocious knots in the timber.

In most timber-producing countries where the State has control over the forests, good silviculture prevents the formation of surplus side branches by reasonable planting distances, appropriate thinning of the

crop as it proceeds to maturity and by proper selection of sites. Such procedure results in tall, sturdy trees, only one-third of whose stems is covered with branches. The former branches have been killed off and the knots occluded when quite small by the restriction of lateral light from adjacent trees. The resulting timber has a number of smallish tight knots in the centre but a wide area on either side which is knot-free.

A distinction must here be drawn between heartwood and sapwood. Heartwood is the inner column of wood in a tree and is usually of a different or darker colour, tougher structurally, and less liable to be affected by the conditions in which, as timber, it may be placed. Sapwood is the outer paler ring of wood which is softer, contains most of the tree's food stored in its thin-walled cells, and is therefore more prone to attack by insects and fungi if fixed, as timber, in unfavourable conditions.

The proportion of sapwood to heartwood in a tree varies, but if it is remembered that the annual growth increment is in the form of an elongated and gradually tapering hollow cone, it will be seen that the area of sapwood can be reduced proportionally to the heartwood by the silvicultural practice already mentioned.

If a tree is exposed to intermittent but recurring forces on one side as might be caused by the prevailing wind or exposure by neighbouring windfalls, it compensates itself by the formation of compression wood which is composed of tough-walled cells in the axis of movement of the bole of the tree. This phenomenon is met at the base of trees, at exposed tops, in buttresses, roots, and on the undersides of large branches.

Hardwoods are those derived from deciduous trees such as Oak, Beech, Ash, Maple. Similar silvicultural principles are applied and indeed they are often grown with conifers since the latter generally take from a third to a half the time to reach maturity; considerations of soil fertility also favour the practice of growing the two types together.

Unless required as a beam or in a heavy roof truss, hardwood is not now commonly used for structural purposes as it is too expensive, but it does form excellent flooring and panelling of a highly durable and decorative kind. Here again the difference in character between sapwood and heartwood should be remembered.

In order to take full advantage of the way in which a tree grows, it is important to consider not only its district of origin but also the way in which it can best be converted to timber for a particular use. For example, if a tree is ripped longitudinally up the centre it will present two surfaces on which the lines of growth are parallel throughout their length. Such a cut, made at right angles to the growth rings, is called quarter- or rift-sawing and gives a homogeneous surface for floorboards and shelves. Plain-cut or flat-sawn timber, on the other hand, presents a face which reveals a number of recurring "V" figures, thus confirming the conical nature of the tree's growth. Such a cut is tangential to the round of the

tree and at right angles to the radially cut quarter-sawn surface. Rift-sawn boards are preferable for flooring because the grain does not " pick up " or splinter in use

In considering the type of wood to be used in building construction, speed of erection as well as strength is bound to be one of the deciding factors in choice of material. To this end Canadian softwoods can contribute greatly. *British Columbia pine* is graded in quality and may be ordered to a specification within fairly narrow limits by reference to these rules of grading. Furthermore it is exported surfaced four sides ; this not only reduces the freight but enables precise measurements to be made beforehand and adhered to in fixing dry interior finish such as plasterboard or flooring. It is usual to stipulate 30, 60 or 90 days air-dry according to the moisture content required for building purposes. Easier handling by carpenters also results from the ready-planed surfaces.

Western Red Cedar is another Canadian timber which, through containing essential oils, is rot-proof and needs no preservative when exposed to the weather. It is used for outside sheathing, subflooring, weather-boarding or puttyless glasshouse joinery. Copper or zinc nails are used to avoid oxidation and corrosion.

Maple makes excellent flooring for squash courts, indoor tennis courts, or dance floors because it has a hard resilience with a surface which wears well.

Several colonial woods can be substituted for better known species ; this has been done during the war where necessity has overcome custom or prejudice. For example, many West African timbers are in ample supply in peace time within a comparatively short sea distance. There are some three hundred different woods which vary from the very soft and light to the very hard and heavy. Of the former *Erimado* weighs only 12 lbs. per cu. ft. and has been successfully tried as a substitute for Balsa. *Abura* resembles Canary Whitewood in general properties and sometimes has a figure like Canadian Birch. It is pale brown in colour, weighs about 34–40 lbs. per cu. ft. when seasoned, and machines and seasons very well. It stains, paints and glues well, cuts easily to veneers and holds nails and screws without tendency to split. It is therefore excellent for interior joinery, plywood, flooring, doors and mouldings ; being fairly resistant to acids, it is particularly suitable for laboratory benches and fittings.

Scented Guarea is an excellent substitute for African or Honduras mahogany for furniture, veneers, turnery, or boat building. It is about the same weight as Abura but fairly tough and strong and more resistant to splitting than the ordinary Guarea.

Iroko, sometimes called African Teak because of its appearance, compares very favourably with English Oak in strength and durability and can be used with success for window frames, sills, stair treads and flooring, or sleepers and fence posts.

Idigbo also compares favourably with home-grown oak, but is available in widths up to 30 inches ; this wood seasons well with little shrinkage or distortion.

African Mahogany needs no introduction. It should not be confused with the true mahogany from Cuba or with the Honduras variety, though it is frequently used in substitution for both of these.

Cherry Mahogany, again not a true mahogany, is tough and more like the Honduras kind but is harder and less liable to split. *Sapele* is another mahogany substitute.

As a substitute for softwoods *Obeche* would be difficult to excel. It compares well with Baltic redwood in bending strength but its stiffness is not so good.

Odoko is in the Beech and Sycamore class, being similar in colour and weight. It can therefore be used for much the same purposes, i.e., domestic woodware, turnery, brush backs, table tops for bakeries, etc.

Okan, also called African Greenheart on account of its resistance to decay and weight (60 lb.–65 lb. per cu ft.), can be used for heavy construction similarly to Greenheart.

Opepe is not so heavy as Okan, being 47 lbs. per cu. ft. seasoned, but is stronger than English Oak and highly resistant to marine borers. It can therefore be successfully used for piling, jetties, groynes, etc.

Ekki, also called African Oak, is regarded as the most durable wood in West Africa and is extremely hard and heavy (60 lb.–70 lb. per cu. ft.). It is stronger than Oak or Teak and can be used as a substitute for Greenheart in wharves and marine work. *Apa* comes in the same category for dock work.

Agba is a large tree with a bole often free of branches for 100 ft. and a correspondingly large girth up to 21 ft. The wood is a light reddish brown in colour and is fairly light in weight (30 lb. per cu. ft. seasoned); it is comparable with Douglas fir. It is 50 per cent tougher than Honduras mahogany and nails, screws, works, stains and polishes well. It will also slice for veneers. It is resistant to decay. It is therefore highly suitable for flooring, joinery, sills and work where wide boards up to 30 inches are an asset.

The above is a short list of woods available from one area of the Colonies whose resources are becoming increasingly available and accessible. They are characterised like most tropical woods by an absence of annual rings, since the growth is almost continuous and only a short dormant period intervenes ; this contrasts with the long deciduous time of temperate hardwoods.

SEASONING

The method of drying or seasoning of any particular wood is determined by reference to a number of factors ; these include the species, method of

sawing, kind of growth, presence or absence of sapwood, frequency and size of knots, width, and thickness of the material.

There is a widespread prejudice that drying in the open air by natural means is the only satisfactory way of seasoning wood. This it not true ; in fact, kiln-drying by artificially accelerated and humanly controlled conditions can be much more accurate and thorough.

There is little distinction in principle between the two methods. They both involve considerations of heat, air circulation and air moisture content or humidity. The object of drying is to reduce the moisture in the timber to a state of equilibrium with the moisture content of the surroundings in which it will finally be fixed, and by so doing to prevent its movement by shrinkage, swelling, warping or cracking. It also prevents the occurrence of mould or of destructive fungus which might invite the presence of wood-boring insects.

It should be appreciated that green Beech, for example, may contain as much as 80 per cent of its dry weight in moisture ; most of this will have to be removed before use. Moreover, dried wood, being less bulky and considerably lighter in weight than unseasoned wood, is easier to handle and costs less in freight. For this reason most imported wood before the war (and only a fraction of marketable wood was home-grown) was dried before shipping to this country, and we started the war with a shortage of kiln-drying capacity. This default has by now been largely rectified by the Timber Control, acting in conjunction with the requirements of the various Ministries, who have stimulated the construction of approved kilns, designed by the Forest Products Research Laboratory at Princes Risborough. Although these kilns were devised and built to cover a national emergency, the community will benefit greatly from their continued use after the war. The successful importation of kiln-dried wood was prejudiced by the fact that it could not naturally travel, whether as deck cargo or in the hold, in the same conditions of equilibrium as those in which it had been dried. There is no doubt that such deterioration in transit gave rise to a good deal of misgiving about kiln-dried timber.

To the timber merchant who has plenty of ground, whose overheads are not great, and whose timber commands a sufficient value at sale, open air drying over several years is both an economic proposition and an art. It is almost impossible to dry wood in the open air below a moisture content of 20 per cent, which means that you cannot use such wood for making panelling, parquet or strip flooring or furniture which is to go into a centrally heated building and expect it to remain in position without moving. The moisture content of such timber would have to be reduced to 9 per cent or less ; whether it was hardwood or softwood, this could be done within a few days in a kiln.

Moisture is held in timber in two forms : the free water, in the cell

cavities and interstices ; and the hygroscopic water, which is in molecular form within the matrix of the cell walls. No appreciable change takes place in the dimensions of wood which has lost its free water, but when the hygroscopic water starts to vaporise, the cell walls, and hence the cells themselves, begin to shrink. It is necessary to control with great care the humidity of the surrounding air, the heat, and the air circulation in a kiln. This is due to the fact that shrinkage within the wood is different in extent in the three dimensions. It is greatest in the direction tangential to the annual rings, i.e., in the width of flat-sawn boards ; it is less in a radial direction, i.e., in the width of quarter-sawn boards ; and it is negligible along the length, except where there are knots around which the grain is uneven, and where unevenness is caused by compression wood or burrs.

There is also the need to distinguish the rate of drying between sapwood, which is pervious, and heartwood, which is comparatively impervious.

The term "case-hardened," as applied to seasoning, means the hard setting of the dry surface of wood while the inside is still plastic and moist. As the inside cools, unequal stresses are set up between the two layers and honeycombing or collapse of the inside of the wood may occur. This happens if the temperature is too high and is sustained too long when the humidity of the surrounding air is too low. The free water is withdrawn too rapidly so that a vacuum is formed within the cell cavities into which the cell walls collapse. The surface of the wood then goes out of true and may have a corrugated appearance.

In the avoidance of such defects during the course of drying, a kiln, with its steam pipes and jets, reversible fans, adjustable ports, and measuring instruments can be controlled manually or by thermostat for any load of timber of whatever species or dimension. While still being an art, modern kiln drying is nearer to a science.

In practice the free water is often removed by stacking in the open air ; parcels sufficient for particular orders are then progressively withdrawn to be kiln dried. In this way the moisture content is reduced to the level most suitable for any particular purpose. For example softwood for carcassing is sufficiently dry at 20 per cent moisture content because, as the building proceeds and the wood becomes enclosed, the place inhabited, and regular heating put on, a gradual equilibrium is established at an average of 14 per cent moisture content after three years. On the other hand, joinery wood for doors and windows should go into the kiln and be reduced to about 12 per cent and primed to prevent moisture absorption during course of erection. Again, panelling near radiators would have to have its moisture content reduced still further to 9 per cent or less.

Of the many types of wood drying kiln, one of the cheapest and most easily operated for both hardwoods and softwoods is that designed by the

Forest Products Research Laboratory, for use in connection with Government contracts during the war. This type is inexpensive to build and cheap to run. It consists of a simple brick building with a flat concrete roof and with sliding doors at one end. Heating coils and water sprays are suspended from the roof in batteries and two electrically operated fans are built high up in one side wall. The direction of the fans is reversible so that the direction of air flow can be controlled. The air current is across the shorter dimension of the kiln, and therefore has less opportunity to become saturated in transit through the stack of wood than ordinarily occurs when air is passed lengthwise through a kiln.

The charge of timber is stacked in the usual way with stickers about $1\frac{1}{2}$ in. square and at 18 in. centres between each row of boards or scantlings. The period of drying varies with the type and dimension of the wood from 24 hours to many days. Hardwoods and pieces of large cross section take longer than softwoods and small dimension stock.

The progress of the drying and the control of the humidity, heat and air flow within the kiln are assessed by the kiln operator who from time to time takes samples from within the stack. These samples are weighed, dried in an oven until there is no further loss in weight and are then weighed again. The ratio between the two weights, expressed as a percentage, gives the moisture content already mentioned.

It is, of course, extremely important to control drying at the beginning while the wood is still very wet because it is then that violent internal stresses may be set up which can cause much *degrade* in the wood. Greater care has to be taken with hardwoods in this respect because of their more complex structure compared with softwoods and their higher value. In general it may be said that as the wood becomes lighter in weight due to loss of moisture so the temperature may be increased, or the air circulation, or both, provided that the humidity is kept sufficiently high to maintain plasticity of the surface of the wood.

Upon this basis a system of suspension of the entire charge of timber in the kiln from the roof by chains was devised in recent years in France. The apparatus is called the Vibo, and consists of a series of levers connecting with the steel beam, from which the charge is hung. This beam is so balanced that an alteration in the gross weight of the timber affects the whole system of levers with which it and the heat and humidity controls and fans are connected and articulated. Thus by the proper setting of the apparatus for the species of wood the drying process becomes automatic and comparatively unskilled labour can be used.

Other systems based on a time schedule and thermostatic control are in constant use but bear no direct relationship to anything but the atmospheric conditions in the kiln, and therefore wood samples have still to be taken and weighed to obtain the percentage moisture content at any time. As this might easily involve the kiln operator in the need to enter the

kiln at a temperature and humidity which he could not stand it seems that the Vibo system, if sufficiently reliable, is pointing to the right solution.

PRESERVATION

The use of timber connectors in outside structures involves either the use of a wood which will not decay or be liable to attack by insects such as *Californian redwood*, or else the chemical preservation of the timber with creosote or some proprietary preservative. Whilst there are many reliable commercially produced rot- and insect-proof substances and liquids, creosote is still the most commonly used ; it is cheap and lasting, generally available, pressure plants for impregnation are conveniently situated, and its use is backed by many years of experience.

The brushing of creosote or almost any preservative on to timber is very temporary in its effect and must be repeated at frequent intervals ; the slightest abrasion of the protective skin, which is at most only ¼-in. thick, is sufficient to allow fungal infection by spores which germinate and spread within the untreated wood beneath. Similarly a wood boring insect could gain entry, and its larvæ develop and bore unseen under the surface of the wood.

Immersion in a tank of creosote which can be heated and then cooled causes good impregnation, especially in the sapwood of softwoods, and is used with success for posts, rails and pitprops. The disadvantage is that very often too much creosote is absorbed and the wood " bleeds " considerably after fixing in position.

The most effective method is by impregnation in a pressure cylinder. The timber is first cut to the required size and shape, including the boring of bolt-holes if possible, loaded into a special trolley, and run on rails into the cylinder. This looks like a large boiler with one end having a special door which can be swung-to and closed by fixing clamps around its edge.

Three processes are in common use : the Rueping or Empty Cell ; the Bethell or Full Cell ; and the Boulton. The latter combines either of the first two with the preliminary extraction, under a vacuum, of surplus moisture from the timber.

Immersion in hot creosote takes place in all three, but with the first the creosote is run out after the pressure by steam or air has been exerted for a sufficiently long time, and then a vacuum is created which exhausts the cells of the wood of the free creosote. The final product does not " bleed " after fixing and is comparatively clean to handle. It is effective in temperate climates for superstructures, but is not suitable for exposed positions in tropical countries or for immersion in water where leaching of the preservative and attacks by marine borers are liable to occur.

The Full Cell process is similar but without the final vacuum and

therefore leaves the wood cells with their walls saturated and the inner cavities filled as well with creosote. The product is proof, as has been tested, against white ants, marine borers, and the more enterprising fungi.

In the Boulton process the timber is first boiled for a period in creosote at reduced pressure, and therefore at reduced temperature. By this means the timber, particularly if of large section, is dried in the outer layers without subjecting it to the same enormous internal pressures as are likely to be caused by preliminary air-drying or kilning; this reduces the attendant possibilities of collapse or shakes. After the initial boiling the vacuum is gradually released, the surplus moisture is drawn off as steam and condensed, and the creosote is drained. Hot creosote is then pumped in and the pressure increased up to 175 lb. per sq. in. and maintained until it is judged that sufficient impregnation has taken place. The cylinder is then drained again and a final vacuum created or not according to whether the Empty or Full Cell process is being employed. The overall time of the operation is from 16 to 24 hours, depending on the degree of impregnation required. By the combination of the Boulton and Full Cell methods it is possible to obtain a content up to 20 lb. of creosote per cu. ft. of wood in softwood baulks of large cross-section such as are used in piling and marine work.

British Columbian pine is particularly well suited for piling inasmuch as it is obtainable in large sections of long length, e.g., 14 in. × 14 in. × 80 ft. It is also, when creosoted, much cheaper than the naturally resistant tropical woods such as *Greenheart*, *Jarrah* or *Turpentine*. However, except in the sapwood, which readily absorbs preservative, even penetration is difficult to obtain to any appreciable depth. To overcome this, incising machines were invented; these comprise a series of rollers, on whose surfaces are situated rows of short, rounded blades, and which are made to rotate and draw the baulks of timber between them, thus making evenly spaced incisions to a constant depth on all sides. The incisions are staggered in longitudinal and lateral arrangement along the grain so as to preclude the possibility of surface checking, and the depth of them does not appreciably affect the strength of the timber. The result of pressure creosoting B.C. pine after incising is an evenly distributed layer of creosote 1-in. to 1½-in. deep all round.

It is often impossible to drive piles to a premeditated depth and bolt holes cannot therefore often be bored before creosoting. This deficiency was largely eliminated by a device invented and patented by Greenlee Brothers of Rochford, Illinois, which can be used for treating bolt holes with creosote after boring through the protective coat when the pile had been driven. The instrument consists of two parts, each of which has a tapered end with a sharp-edged screw thread on it to facilitate screwing. The one part is simply a solid bung with twin handles; the other part is a strongly made syringe, the barrel of which has a funnel at the outer end

near the plunger handle. This funnel is a fixture and enables hot creosote to be poured in after the nozzle has been screwed into the bolt hole. The plunger is withdrawn against a strong spring, the hot creosote poured in, and the handle gradually rammed home until the creosote has been forced into the wood surrounding the hole. The combined spring and manual pressure is said to reach 120 lbs. per sq. in. which ensures adequate protection.

An additional effect of creosoting under pressure is to seal the wood surface so that the tendency to swell or shrink in the open is reduced. The fire hazard is discussed later under fire prevention.

DEVICES WHICH ASSIST CONSTRUCTION

The weakest part of a structure built of wood which is to resist considerable stresses is commonly considered to be around the bolts at the points of juncture with the wooden members. This is, of course, because it is necessary to cut holes of ½-in., ¾-in or 1-in. in diameter to enable bolts of sufficient strength and bearing in cross-section to be fixed. Bolts of larger diameter are not commonly used but are duplicated by a number of smaller ones, in order to conserve the strength of the timber in the transmission of forces from one material to another. A number of steel devices have been patented which increase the bearing area of wooden joints while decreasing the amount of wood to be cut away and the number of bolts necessary.

These devices are called Timber Connectors and one is illustrated in the drawing (Fig. 36) on page 108. The " Bulldog " connector consists of a plate of steel stamped in circular, square, or rectangular form with a centre hole through which the bolt is to pass, and with edges at the perimeter turned off at right angles to form triangular teeth. The " Teco " connector is a steel ring about ¼-in thick and ¾-in deep of double-wedge-shaped section whose centre is thicker than its edges. The diameter varies and the ring is split at one point into a tongue and two shoulders.

The method of fixing both types is similar. A connector is placed between two wooden members to be joined and directly over the bolt hole through which a bolt is inserted and screwed up tight against the large square washers on either side. This draws the members close together and brings the connector into bearing around the bolt. In this way, if a " Bulldog " is used, its teeth are forced into the wood on either side until the adjacent pieces are flush. If a " Teco " split ring connector is used the two wooden members have first to be channelled with a special scoring bit; this has a centring boss with a stop shoulder on it which is inserted into the bolt hole. The shoulder prevents the circular groove from being cut deeper than necessary. The split-ring is inserted by springing it open with expanding pliers to fit the groove, whose circumference is slightly larger

than the connector when at rest. The reason for this is that the connector can take up any slack which might be caused by shrinkage of the wood or can expand further if it swells. In either case no subsidiary stresses arise.

The double-wedge shape of the cross-section of the " Teco " ensures that the thickest part comes at the point of greatest shear force. The bearing surface has been increased to that of the connector ring, and with the " Bulldog " the bearing is increased by the teeth at the outer edge, the rim of the centre hole and, to a lesser extent, by the plate against the two wooden members.

The Siemens-Bauunion hinged connector system is a further development of the same principle. It consists of a combination of several connectors toothed on one side only and with the bolt hole in the centre of radiating arms which form a toothed grid. On the other side of the grid the bolt hole protrudes to form a circular flange whose object is to articulate with the inside of a bolt hole in a steel strap. Where a series of several members have to be joined together these straps, which are flanged at their ends at the point of junction, are joined by the flanges fitting together beneath a circular channelled steel cup through the centre of which a locking wedge passes. By this means free rotational movement of the members under elastic deformation of a truss is permitted, and compression or tension is transmitted without secondary internal stresses.

Tables of safe loads for various sizes and types of connectors and woods, and spacing distances and margins are contained in the *Wood Handbook* issued by the Superintendent of Documents for the U.S. Department of Agriculture, Forest Service. Reference to this book can be made at the Timber Development Association, the Institution of Civil Engineers or direct from Washington D.C.

By means of timber connectors, tensile steel bolts, and structural strength tables for various types of timber, spans 200 ft. and more have been constructed in trusses, and built-up girders for bridges, and roofs of factories or halls. Radio and wireless telephony masts of the cantilever and self-supporting types, some 300 ft. high have been built in this country with the aid of timber connectors and creosoted softwood during the past ten years. In America and Canada these devices are of longer standing ; they have been employed in wooden railroad and highway bridges which have seen heavy service for many years, and have been found far more satisfactory than large steel gusset plates and angle irons.

LAMINATED WOOD

A logical development of building technique making use of wood in those countries which do not produce timber of large dimensions was the formation of beams of some depth and considerable length by building

them up of short lengths in laminations which overlapped each other. These were either nailed, bolted, or glued, according to the thickness of each layer and the desirability of bending. By alternating different species and grains a high strength to weight ratio could be achieved. An example of this type of construction was given by the solid arches of rectangular section used by the U.S. Forest Products Laboratory in the building of a warehouse and testing plant at Madison, Wisconsin. The laminations were each $\frac{9}{16}$-in. thick, glued together and pressed to form a combined wall and roof support at 16 ft. centres and spanning 46 ft. The complete arch consisted of two boomerang-shaped sections each of which was thicker at the " knee " bend than in either arm and had a base thickened at the footings ; the two were joined at the apex by a bolted steel plate.

The roof decking was made up in units each consisting of a flat box beam panel 4 ft. wide and 16 ft. long. Each unit consisted of an upper sheet of 5-ply, $\frac{5}{8}$-in. thick Douglas fir plywood glued to three longitudinal joists of 2 in. × 6 in. situated one in the centre and one on either edge with headers at each end. The lower sheet was of 3-ply, $\frac{3}{4}$-in. thick, glued to the lower edges of the joists. Each unit was slung into position by a derrick and fixed to its neighbour, resting on the arches by splines in the side of the outside joists. The top sheet was left 6 in. short of the end to facilitate nailing of the bottom sheet directly onto the arch. The 12-in. gap was filled in afterwards and the whole decking tarred and gravelled.

The laminations of the solid arches were glued up to a width of $11\frac{1}{2}$ in. with a thickness of 12 in. at the base above the footings, 24 in. at the knee at eaves level, and 8 in. at the apex. Flanged plate bearings at the footings anchored the base of the arches. A roof load of 45 lbs. per sq. ft. was assumed and a possible side thrust on the footings of 10,000 lbs. was allowed for. Two large double sash windows were fixed in each bay.

Each layer in the arch beam consisted of pieces $\frac{9}{16}$-in. thick × 4-in. to 8 in. wide, and from 6 ft. to 16 ft. long, the edges being staggered and scarf jointed.

Two other types of roof supports were also tried on an experimental scale : double plywood I-beams built up of laminations similar to the above, and trussed arches constructed with timber connectors and ordinary solid timber. Although the cost of timber connectors was found to be high in relation to normal bolt and plate connection, this was offset by the ability to use chord and web members of smaller cross-section and to reduce labour costs by using considerably fewer bolts in fixing. In fact the 9 large arches were erected by six men with a hoist in $1\frac{1}{4}$ days, the root panels in 2 days, and the side panels by four men in less than 3 days. All units were prefabricated and brought to the site in sections ready for erection.

PLYWOOD

A natural further development from lamination came from the interleaving of veneers with glue to form plywood under pressure. Within the last ten years tremendous strides, hastened latterly by the war, have been made in structural plywood manufacture by research on waterproof glues, glueing technique, pressure, drying and moulding.

For example a beam of even depth and thickness can now be constructed in plywood so as to withstand the increased stresses at certain points in its length by increasing the plies at those points and super-pressing to the same bulk as the rest of the beam. This enables greater working space to be given around the beam at its ends and elsewhere which, in a factory with overhead shafting, is important.

By the arrangement of the grain in adjacent plies, the choice of wood, type of glue, and the pressure used, plywood can be designed to meet most requirements. For example, in the construction of wooden cogwheels for use in wool and cotton machinery, or nuts and bolts for electrical apparatus the plies are usually arranged so that successive grains occur at angles of 15° to each other in order to ensure even wear.

One very important development which makes it possible to use plywood for outside facing or in moisture-laden atmospheres is the adoption of plastics cements. These are described in section II of this book which deals with plastics.

Plywood for less specialised and indoor purposes is usually bonded with vegetable or animal glues and dried by steam-heated platens in the presses through which it passes, and afterwards by separate stacking in currents of warm air. The size, thickness, and number of layers in a plywood sheet depends upon ease of handling and fixing, but panels up to 16 ft. × 8 ft. in Douglas fir could be obtained in peace-time, and were admirably adapted to quick and dry wall covering over 2 ft. × 4 ft. studs at about 18-in. centres. By this construction a series of airproof units is made, forming an excellent thermal insulator. A wall of $\frac{3}{8}$-in. thick plywood on the inside nailed over building paper onto studding at 16-in. centres with external grade waterproof plywood on the outside has a heat transmission coefficient of 0·195 British thermal units. In addition to its insulating quality, the dry construction gives more living comfort than a brick or concrete-walled room with a plaster and lath finish. Wood is itself a non-conductor of heat; in summer, the room will therefore be cooler, and in winter will be warmer. For unit construction, as in factory-produced building sections, plywood makes a rigid easily handled unit, light for the area covered.

Acoustic tests show that plywood compares favourably with other materials which might be used in similar construction, in both sound absorptive and sound deadening qualities. Transmission of sound from

room to room can, of course, be further prevented by the use of Cabot quilting, woodwool and cement slabbing or by employing one of the mineral granular substances which can be poured between the studs. The latter have the further advantage that they are also highly fire-resistant.

Plywood wall finish can be varied in a number of ways. If the recurring open joint between panels is not acceptable, the space can be filled with special putty or plastic wood filler and sanded to a flush finish. Additional strength can be obtained by taping the joint ; this will prevent cracking. After applying a resin sealer to prevent rise of grain, a plastic or water paint can be used to give an effect similar to that of a plaster wall, but it will be stronger and more rigid.

Before enamelling, plywood bathroom or kitchen walls should first be primed with a thinned flat white oil paint. Over this, muslin is stuck with lump-free wallpaper paste and, when dry, given a coat of glue size. When this is dry, the enamelling can be done.

Exterior grade waterproof (resin sealed) plywood on outside walls should be finished by using a ready-mixed paint, the first coat of which is reduced by adding one gallon of raw linseed oil per gallon of paint. Subsequent coats may be of the ordinary paint.

Plywood in ¼-in., ⅜-in., or ½-in. thicknesses is also very successful under Western Red Cedar roofing shingles or composition tiles where good nail holding and snow loading capacity is required. Sub-flooring of the same thickness of plywood affords an excellent surface for composition or parquet flooring (laid in mastic), adds to the floor loading capacity and resilience, and provides a working platform during building.

The principal grades in which Douglas fir plywood is ordinarily available are as follows :—

Good face : has the whole of the side in one piece, practically clear of knots, and of a veneer cut from the heartwood.

Sound face : has two or more longitudinal veneers in which sapwood, stain (not caused by incipient decay, but mineral or pitch stain), and neat patches (where large knots have been removed and holes filled) are allowed and has a completely smooth finish.

Good face is used for panelling where a good figured finish is wanted but sound face is used for painted walls and ceilings. Panels are made " good 2 sides " (G2S), " good one side (G1S), " sound 2 sides " (So2S), and the cost is proportional.

FIRE PREVENTION

One common belief is that a wooden structure will easily catch fire. This notion probably springs from the fact that the domestic everyday fire in the grate is lit with sticks, and that, in dry summer weather, forests some-

times catch fire. It exaggerates the combustibility of wood. In the first place, domestic firewood is of small size and dry, and has to be coaxed alight with paper and a proper draught beneath it ; in the second place it is the dry tinder of dead underbrush, leaves, bracken or heather which are fired either by a discarded glass bottle concentrating the sun's rays, or by sparks from a railway or road engine. The casual cigarette end and unquenched match also add their quota.

Most buildings, whether business or residential, have inflammable hangings or fitments—curtains, carpets, linoleum, furniture coverings, furniture padded with kapok or horsehair—and it is upon these that a fire first feeds and gains sufficient proportions and intensity to ignite wooden panelling, furniture itself, window frames, floorboards, joists and rafters.

In order to conserve ordinary fuel, many of us have bought logs to burn in our grates and have probably learned for the first time how slowly wood, when fairly thick, will burn and how much draught is necessary for it to burn brightly. Yew logs are difficult to burn at all and so is bulk Beech. Softwood burns more easily than hardwood, but in any event the reason why a substance burns is because of the inflammable gases it contains.

With creosoted softwood timber of 5 in. × 5 in. and upwards ignition of the surface is not so easy as might be imagined, and when it does occur the tendency is for the creosoted area to burn on the surface and then to go out. This is because the creosoted wood, unless fanned by a stiff breeze, makes a dense carbon which deters inflammable gases from within the wood from igniting and feeding the flame on the surface. The function of the draught is to bring fresh supplies of oxygen and inflammable gases to the surface ; without these the flames would die from lack of nourishment. This property of carbon is one of the recognised means of making timber fire-resistant.

Fire Preventive Substances

Timber may be impregnated with fire-resistant solutions in much the same way as preservatives ; where the cost is justified, the two processes can be done at the same time. One such fire-resistant substance is monammonium phosphate which induces a very rapid formation of surface carbon sufficiently thick to preclude the volatile inflammable gases from within from reaching the surface ; smouldering is thus prevented.

A high concentration of this salt (5 lbs. of dry monammonium phosphate per cu. ft.) is the most effective of all fire preventive substances inasmuch as it is not only prevents flame propagation and smouldering but is non-corrosive to metals and is hardly hygroscopic (i.e., does not make the wood surface damp by assimilating moisture from the air). It is combined in some proprietary substances with boric acid because the latter is even less hygroscopic and non-volatile and therefore tends to fix the monammonium

phosphate in wood from which it might otherwise be leached out under damp conditions.

In the main it may be said that impregnation under pressure with a fire-retardant salt solution is more effective than a surface coating with fire-resistant paint or other finish. This has been proved by wartime experience ; the chemical in the wood has been found to form barren charcoal in the presence of incendiary bombs sufficiently long to enable firemen to reach and extinguish the bombs. Fire resistant paints have also proved effective against incendiary bombs, though for a shorter time.

Untreated timbers which have a very high fire resistance are mostly those imported from the tropics, etc. Examples are *Greenheart*, *Jarrah*, *Padank*, *Pyinkado*, and *Teak*. One of the reasons for their resistance lies in the silicate deposits found in the cell structure ; this also makes them resistant to the attacks of some marine borers and insects.

NATURAL PRESERVATION AND FIRE PREVENTION

Timber in a building can be very largely preserved against the possibility of decay and insect attack by forethought. Careful periodical inspection and preventive measures in the timber merchant's storage yard, quick transportation from the forest after felling (or importation) to the conversion mill, and proper stacking and sticking before and after kiln drying or open air seasoning are all necessary. A knowledge of the methods employed on the premises of the merchant from whom timber is bought is therefore a precaution to be recommended in selecting wood. This implies personal supervision by the architect or engineer but often it is a considerable economy over the common practice of accepting the lowest tender.

A fungus can only thrive in the presence of moisture or a damp atmosphere, food material such as carbohydrates, equable temperature, and usually in the absence of light or direct daylight. Such conditions are often found in cellars, badly ventilated sub-floor spaces, the interior of cavity walls without adequate damp courses, beneath a leaky roof and so forth. It is, of course, one of the architect's jobs to prevent such conditions occurring and to rectify them if called upon to remodel or repair an old building. What is not commonly realised is that the householder himself may be at fault after the house has been perfectly well designed and built. For example, ventilation gratings are sometimes blocked on the outside by piling earth from flower-beds against them or by the growth of thick bushes and leaves collecting behind them. Such an occurrence, coupled with the laying of linoleum or other floor covering fitting close to the floor boards on the ground floor, forms conditions ideal for the development of dry-rot. The wood is unable to " breathe " on its upper surface, and the underside presents the conditions suitable for spore germination

and growth of the fungus. If, on the other hand, all the air is prevented from reaching floor-boards (which are sufficiently dry before laying) by fixing them in mastic on a solid concrete foundation which has had time to "cure," and with rubber, linoleum, cork, or a composite covering over the wood, the result will be as satisfactory as good ventilation. The reason for this is that the conditions are dry and devoid of air except that which is static within the wood. Without air a fungus cannot develop.

Surface mould or "Blueing" should be distinguished from incipient decay; the former is harmless and does not affect the strength of wood. It is, however, an indication that conditions are suitable for the development of fungi.

Sapwood is more readily attacked by fungi and some insects than heartwood. Its cell walls are not so hard or thick as the heartwood, and those of the latter often contain a natural resinous preservative. Sapwood also contains a higher percentage of the stored food of a tree upon which the fungus can more readily feed. Wood boring insects often have an instinctive choice for sapwood, and decay assists in paving the way for their attack. This may operate in two stages, first by the boring beetle and later its larvæ which develop from the eggs. Again, the fact that sapwood will always be on the edge of structural wood implies that in decaying it becomes friable and inflammable at the least dimension.

STAVE PIPING

One of the specialised adaptations of creosoted wood was invented by a Canadian civil engineer, H. Nolan Macpherson, who designed a pipe which could be easily built up from stock timber sizes. The units of construction are staves planed down from 2 in. × 4 in. of the sapwood or heartwood of *Douglas fir*, *White pine*, *Hemlock* or of any softwood which will absorb creosote under pressure. This type of piping was also made by imitators in *Californian Redwood* and other rot-resistant woods but was more expensive.

The units are of three standard lengths, being either 2, 8 or 10 ft. long for reasons of assembly which will be explained later. Each stave is so tongued and grooved as to allow the building of a pipe from 12 in. to 30 in. inside diameter without altering the design but merely by adjusting the number of staves from 14 to the circle in the former case, to 32 in the latter. The staves are held together by steel hoops of T cross-section tightened around the circle by bolts. One such bolt per hoop is sufficient to ensure a water-tight pipe.

A section of a stave shows that the tongue is rounded and about as long as it is thick. The shoulders of the groove are not square but sloping so as to allow sufficient articulation to take place in constructing pipes of varying diameters.

The spacing of the hoops depends on the diameter. The first hoop is, however, always placed one foot from the end, the next hoop at a distance of 5 ft. on 12-in., 15-in., and 18-in. pipe ; or at intervals of 4 ft. on 24-in. pipe ; or 3 ft. on 30-in. pipe, intermediate diameters being proportionally fitted.

Two combinations of the different lengths of staves are required to make up the pipe and the staves are staggered in the right lengths so as to ensure the maximum strength after the units have been slid into each other. The method is best illustrated by an example for a culvert, say, 20 ft. long showing the arrangement of the different lengths of staves in alternate courses :—

2 ft.	8 ft.		10 ft.
8 ft.		10 ft.	2 ft.

Short staves always alternate with long inside the first hoop so as to obtain satisfactory jointing ; similarly a pipe is finished with 2 ft. staves alternating with longer ones.

In the above way it can be seen how easy it is to fit any length of continuous pipe which can then be adjusted in length or diameter to suit altered conditions a number of years after the first laying.

The pipe may be assembled by two men in the trench or a 40-ft. section of 12-in. pipe can be rolled by the same labour if it is desirable to assemble before laying.

The piping is flexible. It can be deflected $2\frac{1}{2}$ in. by a load of 6 tons applied on a 6-in. face immediately above the resting place when there is no adequate support. Therefore in the event of subsidence beneath the pipe, or insufficient covering above it, it will not crack or leak or disintegrate. Being made of wood it is immune to the dangers of freezing inseparable from concrete or iron pipes. Furthermore water will not freeze so rapidly in wooden piping as in concrete, and the expansion resulting from ice formation will not crack the pipe.

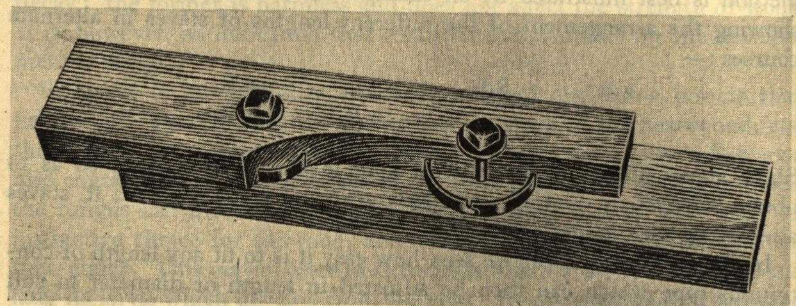
Macpherson and similar piping have been in continuous use over long distances in America, Canada, and elsewhere for some thirty years without any appreciable loss of efficiency. It has been shown that liquids flow through such piping more rapidly than through corrugated steel piping. The hoops are made of copper steel which is proof against the corrosion of soil acids or alkalis. Concrete is liable to gradual disintegration under similar conditions.

When wood-stave piping has outlived its usefulness it can be dismantled and used elsewhere.

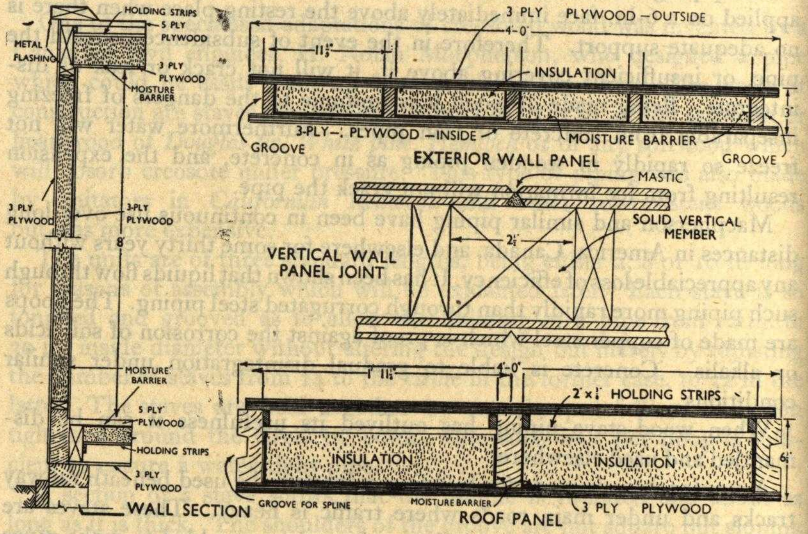
A stouter stave is made for building culverts to be used beneath railway tracks and under main roads where traffic is heavy. These staves are prepared from 3 in. × 6 in. timber and can be assembled to make pipes from 36 in. to 60 in. in diameter. They are capable of carrying moving

loads such as are transmitted by the passage of trains above the track bedding.

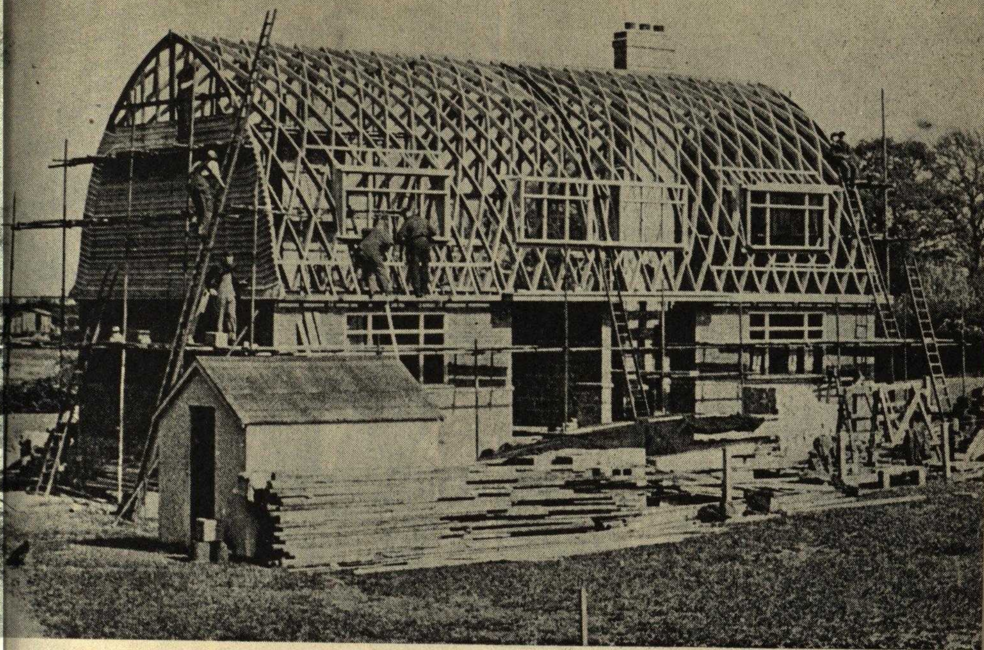
Seeing that importation of prefabricated wooden houses from America has been carried out under Lend-Lease, stave piping could well form an additional adjunct for water supply, drainage or sewage, particularly in country districts. The short lengths of wood involved contribute greatly to the cheapness since they are largely off-cuts. Creosoting could be done in the country if the wood used requires preservation.



36. Cutaway section, showing Teco split-ring timber connectors wholly embedded in the facing members. The tongue-and-groove split, which is forced slightly open by installation, allows for subsequent movement in the timber. The ring spreads the load over practically the entire cross-section of the wood.



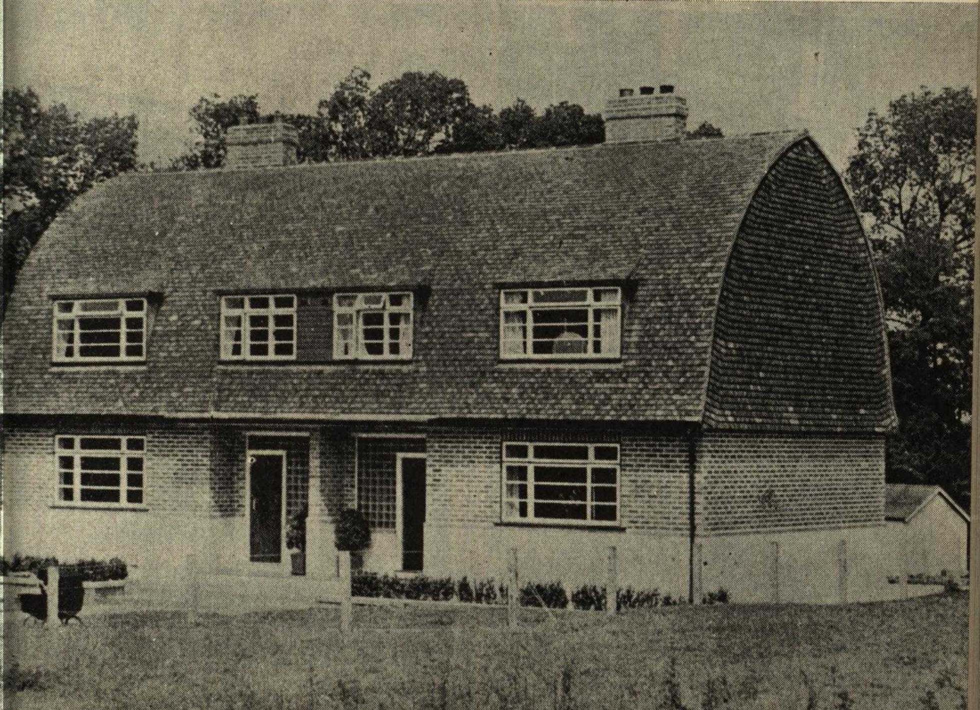
37. Details showing the method of construction of a prefabricated timber house developed by the American Forest Products Laboratory, Madison, Wisconsin.

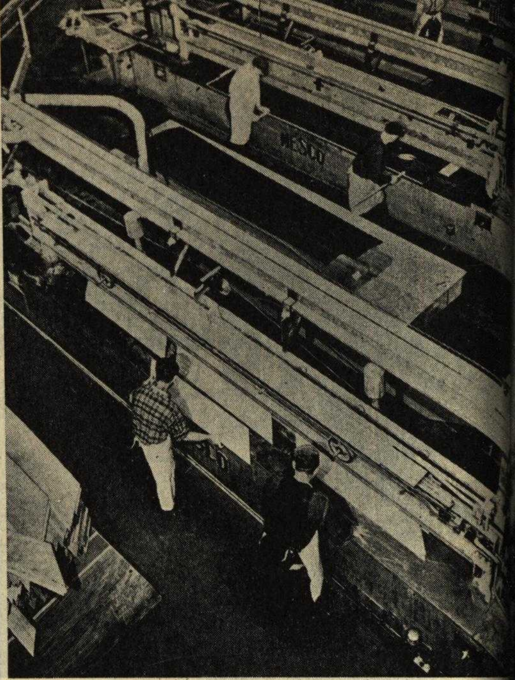


The Lamella type of roof as adapted for house construction.

38. The roof still exposed.

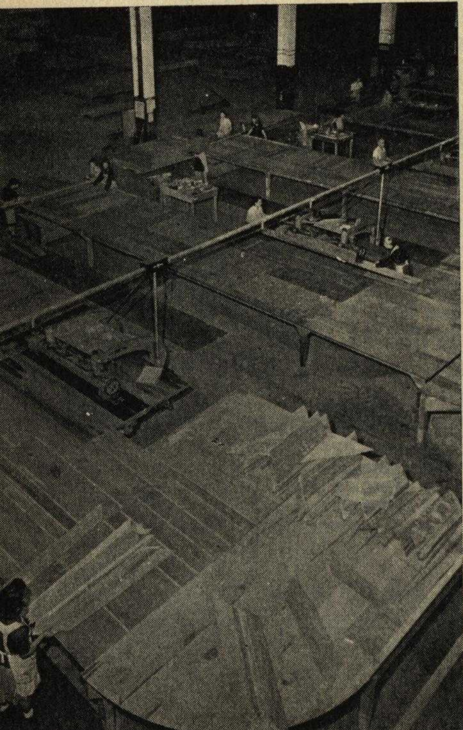
39. The completed house.

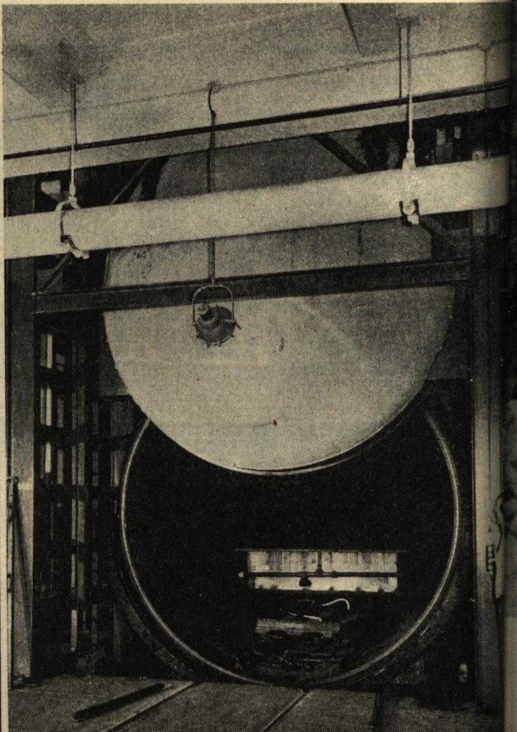




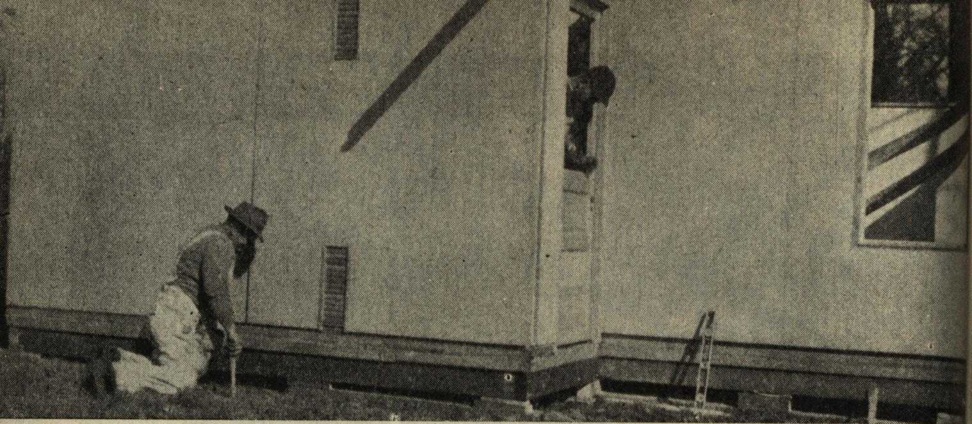
Four stages in the manufacture of resin-bonded plywood.

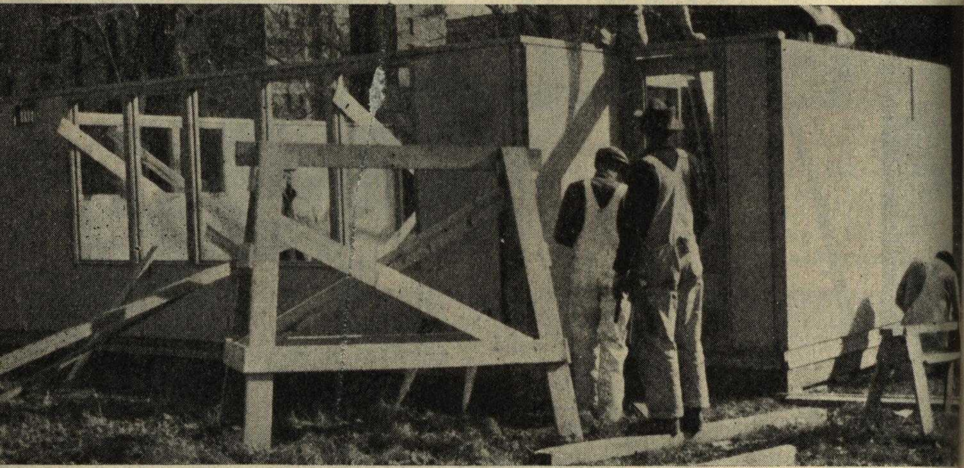
40. Wood veneers on the clipping tables where defects are clipped out and edges straightened.
41. Edges of veneers being spread with bonding resins and jointed.
42. Individual veneers being spliced into large sheets by edge-gluing.
43. The plywood sheet enters the autoclave for curing under heat and pressure.





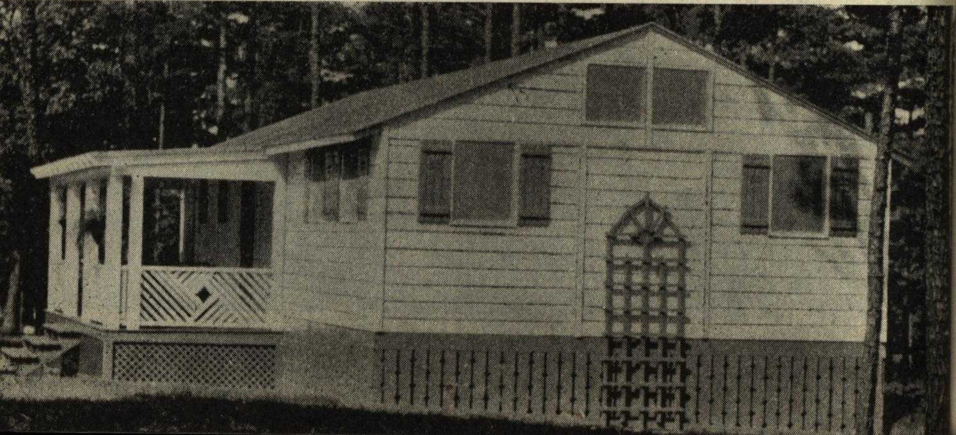
44. Swedish prefabricated timber house with three bedrooms.





45, 46. Two stages in the erection of the American timber frame prefabricated temporary house as supplied to this country under Lend-Lease.

47. American Portable House. Adapted from the basic design for the C.C.C. camp portable barracks, Atlanta, Georgia.



SECTION IV

AN OUTLINE OF PREFABRICATION

PREFABRICATION has come into the news in the past few years, and to many people it is thought of as a complete novelty. In reality, the custom of undertaking as much of the fabrication of houses as possible in workshops is as old as the hills.

What is new is the extension of standardisation, which enables the workshops to take advantage of mass-production methods. By assembling on the site components mass-produced in the workshop, the building industry is expecting to be able to effect a great saving in cost and in man-hours.

Mr. Dex Harrison gives a description of the past history of prefabrication, in which he has to show that not only in this country but throughout the world the full benefits of prefabrication have yet to be reaped. He next discusses the outstanding problems liable to delay the full realisation of this modern technique which is needed to bring building practice more into line with other industries of our time. He reveals that we are still hampered by a distressing lack of uniformity of dimension, which prohibits the full standardisation of components.

Prefabrication is not a substitute method for building fake versions of traditional houses. The new technique demands a new approach to design, and depends on the selection of those materials which are most suitably adapted to machine production. The author is somewhat sceptical of the future of precast concrete in prefabrication, arguing that its use in this form sacrifices its inherent assets—plasticity and continuity of structure. Moreover, concrete slabs are too heavy to be readily transported far from their point of manufacture. He looks rather to the metals, particularly in their sheet form. As he points out, however, the selection of materials is not a matter for arbitrary choice by the designer but depends on considerations of availability and economy.

AN OUTLINE OF PREFABRICATION

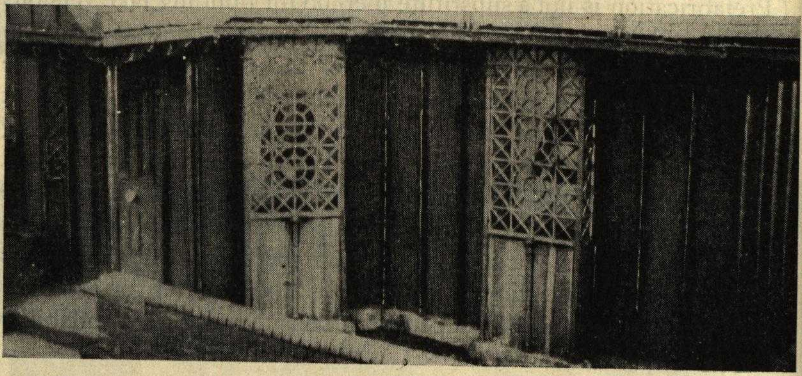
By D. DEX HARRISON, A.R.I.B.A., A.M.T.P.I.

A GOOD deal of mistrust and unpopularity appears to attach to the term "prefabrication," and writers are often at pains to rename the movement as though it would thereby smell the sweeter. Prejudice against the term springs partly from ignorance as to what it implies and partly because its use is often identified with temporary structures such as army huts and similar flimsy buildings. The word has suffered further by being linked to the temporary housing programme. So many people have almost wantonly identified prefabrication with the temporary and shoddy that it is necessary to stress at the outset that the movement is a fundamental and permanent one which has been developing for over a hundred years and is revolutionizing building technique, from the cheaper temporary structures to the most expensive types of luxury building.

Used in its widest sense, the term prefabrication covers all processing of materials which does not take place at the actual building site; it is the trend toward factory production of buildings and building products.

THE DEVELOPMENT OF THE MOVEMENT

"*And the house, when it was in building, was built of stone made ready at the quarry: and there was neither hammer nor axe nor any tool of iron heard in the house while it was in building.*" (Kings 1, 6). King Solomon, indeed, was not unaware of the advantages to be gained by prefabricating. We could go further back, for the burnt clay bricks of the Sumerians were,



48. Tipton Green No. 1 Lock House. The first iron house on record. (pre 1830.)

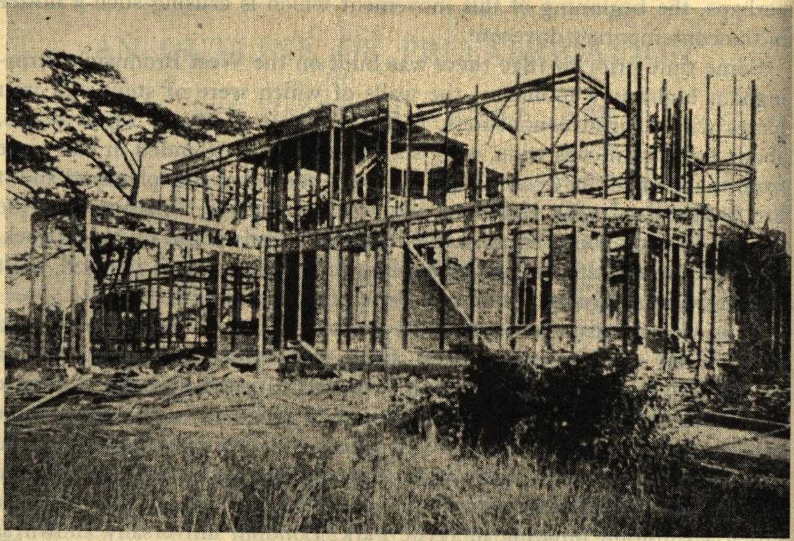
perhaps, the beginning of this movement which is causing such a flutter in the contemporary dovecote.

Some time prior to 1830 there was built on the West Bromwich-Birmingham highway a tollhouse, the walls of which were of stout cast iron plates with flanged connections, bolted one to the other. These plates, about eighteen inches wide, were set vertically and extended in one piece from the floor to the eaves. The interior of the house was plastered and it had a slate roof with elaborate cast iron ornamental finials around the edges. Round about 1870 it was pulled down and rebuilt at No. 1 Lock, Tipton Green, Staffordshire, and when finally dismantled in 1926, so it is said, was in as good condition as when first it was built.

This was the first iron house on record anywhere in the world and present day prefabrication dates from this unobtrusive and almost unrecorded building. The first half of last century was a period of intense vitality in this country and too little credit is given to the remarkable achievements in the technique of using new building materials developed at that time. The production of cast iron and glass in sizable panes opened up immense prospects to those pioneers and in 1851 Paxton built his Great Exhibition building in Hyde Park, London, universally known as the Crystal Palace. This was the first large scale demonstration of mass production and the use of repetitive processes in building. The structure consisted of cast iron columns, beams and lattice girders, clothed externally with glass set in cast iron moulded frames. Fabrication took place in various workshops in Birmingham and the parts were transported and erected without difficulty in London. It is said that the whole of the glass, which was in panes of a standardized size—the largest that could be made economically—was delivered in six weeks.

This building, which was greatly admired at the time, ushered in the modern movement in architecture, but the white flame of experiment and progress died down in this country and the next effective contributions to building technique are to be found in America. Here, the new-fangled skyscraper provided an impetus towards serial production which has continued right up to the present time, in such forms as standard window types, prefabricated spandrils and plumbing runs, and so on.

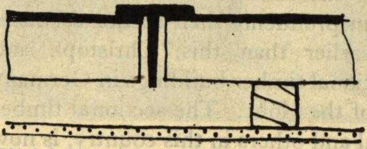
In 1890 Nils Poulson, an ironmaster, built a house for himself in New York which had a steel frame with stanchions set about a yard apart and which was faced with copper. This house, too, when pulled down after a life of 40 years, was found to be in excellent condition. Two years later, Messrs. Hodgson of Boston began producing their sectional houses in timber, although twenty years earlier than this, Christoph and Unmack had begun making similar sectional timber buildings in Germany which they began to ship to all parts of the globe. The sectional timber industry, taken up by Boulton and Paul and others in this country, is now a recognised development in building in almost every country.



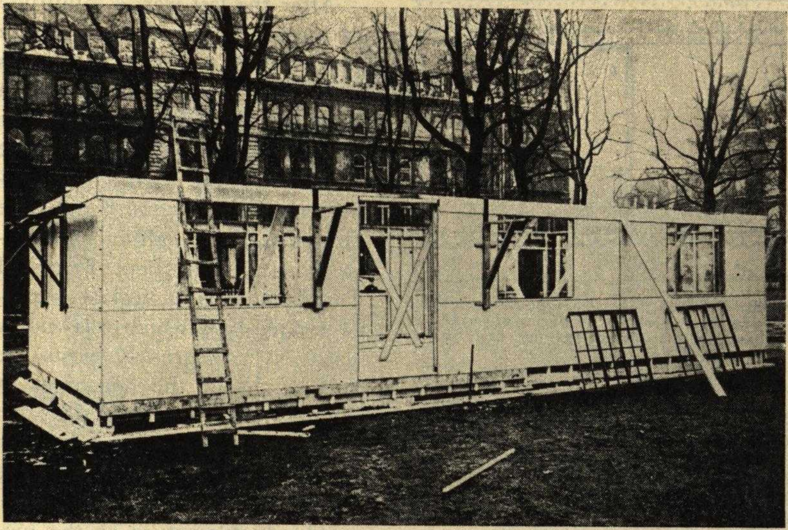
49. Nils Poulson steel framed house in New York, built in 1890, being demolished after a life of 40 years. It was still in excellent condition.

At the turn of the century, then, people were beginning to think of means of building houses which could be used as an alternative to the laborious process of erecting in brick at the site, and occasional steel framed houses were put up in the United States prior to the first world war, whilst experimentors like Grosvenor Atterbury were working in concrete.

The cessation of building during the war years, 1914–1918, and the decimation of the building industry resulted in a shortage of houses in all countries and in Great Britain, in 1920, a nation wide effort was made to produce housing in the mass by any suitable means. The means were steel and ferro concrete, both materials still in an embryonic stage of development. Steel houses such as the Weir, Atholl and Braithwaite, used hot rolled steel sheets of heavy section, 11 or 12 gauge ($\frac{1}{8}$-in.) thick, such as had been produced in large quantities for shipbuilding. These sheets were used to form the exterior face of the wall and were painted. They obviated the use of brickwork and thus fulfilled their function by introducing non-building labour into the building industry and enlarging the capacity to build houses. This was, indeed, their downfall, for the building trade unions took exception to build-



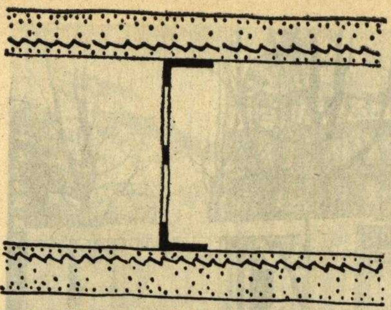
50. Atholl steel house. Steel framing and steel exterior panels. 1926.



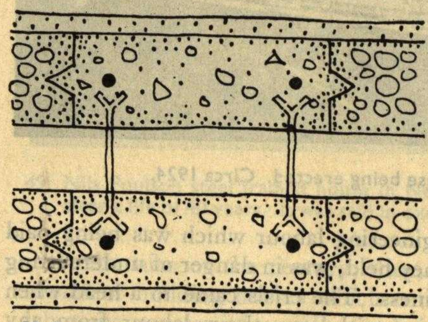
51. Weir steel clad house being erected. Circa 1924.

ing work being carried out by engineering labour which was being paid at the time at lower rates and, so they held, was in danger of undercutting them and driving them out of business. The crisis came to a head when the building unions threatened to withdraw their labour from any Council which continued to erect Weir houses; under this threat few Councils would proceed. Nevertheless, up to 1926 many thousands of steel houses had been built; though these suffered a good deal of mud-slinging at the time, recent investigation has found the bulk of them to be in very good condition and to have a long expectation of life ahead of them. Trouble was at first experienced from corrosion, especially where insufficient care was taken in protecting the plates during erection (for instance, they were even used as temporary trackways for wheel-barrows and their protective coatings worn off) and they had to be re-painted at frequent intervals, but later, the process of paint harling was adopted. This has been found to last up to twelve years without renewal; the steel is first painted and then, whilst it is still tacky, sprayed with granite chips which have been dipped in paint.

The Dorlonco houses, also built in great numbers during the same period, used a steel frame with close spaced studs which were then stuccoed on a backing of metal lathing. Some trouble was experienced with some of these houses where the steel lathing, due to insufficient cover, corroded and caused the stucco to collapse but this type of construction has been widely used, apparently without trouble, in many countries.



52. Bar-Z-Gunite. American house with light steel framework and rendering of cement on expanded metal inside and out. Early 1930's.



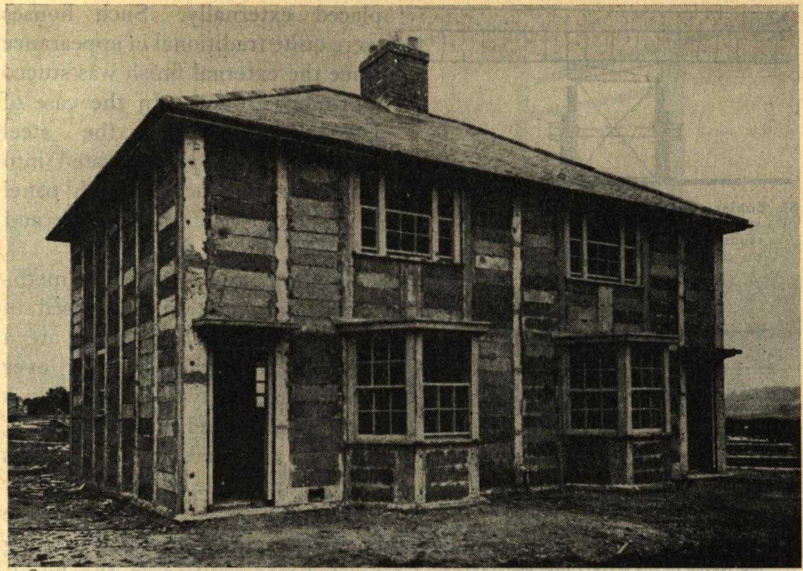
53. Boot Pier and Panel House. Precast concrete piers, with precast cavity wall slabs of breeze concrete between. 1924 onwards.

After the last war, a multitude of types of concrete houses were also evolved, and many thousands were built. Not all attempted a high degree of prefabrication, the majority being of the concrete block type, the method of construction of which differed little from that of the traditional masonry houses. The Boot Pier and Panel house is typical of a prefabricated type which was widely used ; it had pre-cast posts the full height of the house set at about 3 ft. 0 in. intervals, with breeze walls set between to form a cavity wall ; the wall faces were stuccoed.

The ductile nature of the material led some sponsors of concrete houses to produce very large pre-cast units, as in the Waller house, but these big units require a correspondingly elaborate organisation for their manipulation and on the one scheme of any extent which used them, a housing scheme at Poole, this organisation was deficient and the firm went into liquidation.

Round about 1926–30 these alternative systems of house building fell, one and all, into disuse. It will be understood that they had been considered in the country as a makeshift and this feeling prejudiced consideration of their intrinsic merits as buildings ; it sprang rather from an innate conservatism among the people so that when the immediate shortage of houses was made good and the normal channels of the building industry could once more cope with the demand the new methods were dropped. They had not, by and large, proved cheaper than comparable brick houses and they could not compete on level terms in view of the prejudice against them.

The mistake had been made by all these hopeful innovators of trying to compete with traditional buildings on their own ground ; the new types were, in design, mostly inferior imitations of brick buildings. No attempt had been made to evolve designs which suited, and took advantage of, the new structural concepts. So utterly bankrupt was the movement in

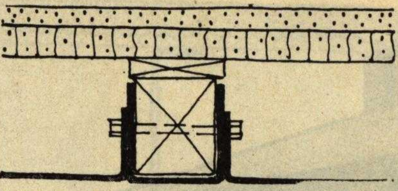


54. Boot Pier and Panel House before being rendered. Several thousand such houses were built between 1924 and 1930.

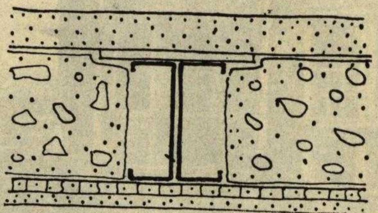
this respect that the new constructions were laboriously worked to the same niggling plans which were in common use for brick houses at the time. It was not realised, and it is still not realised, that plans and designs suitable for brick buildings, which can be cut and chopped about in extraordinary detail, are totally unsuited to the factory-made articles of standardised size which require the clearest and simplest planning for their economical use.

The scene shifts to Germany. Owing to the economic ravages of war, the housing drive in Germany did not get well under way until the middle twenties and, as in this country, a shortage of skilled building labour combined with a surfeit of productive capacity in steel resulted in a similar drive for alternative forms of construction. Experience gained in this country was there utilised to the full and designs which took their inspiration from the Weir house, for example, are to be found.

For small houses three main types of construction were used ; close spaced frame, open spaced frame and loadbearing panels. Infilling between the framing was frequently of lightweight concrete slabs ; the exterior was afterwards stuccoed. Considerable inventiveness was displayed in many of these systems and one, Bohler Stahlhaus, of Vienna, used steel panels, which were structural, as the *inner* face of the wall to get over the condensation difficulty always experienced when the steel is



55. Bohler Stahlhaus, Vienna. Weight bearing steel panels of cold formed steel used to form studs and interior lining. Exterior rendered on top of an insular lining. 1936.



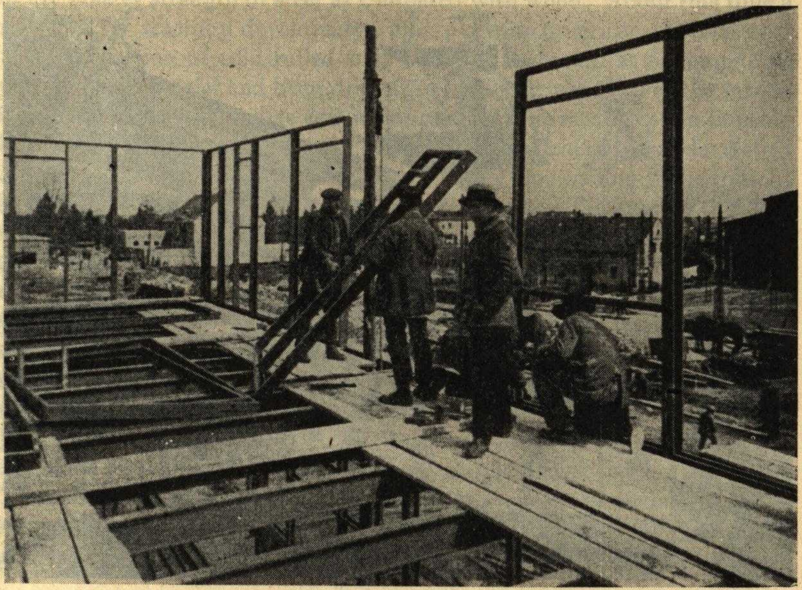
56. Deutsche Stahlhaus. Cold formed steel frame fabricated in the factory into panel sections and bolted or welded at the site. Infilling is of pre-cast pumice slabs. Exterior rendered. 1928.

placed externally. Such houses were quite traditional in appearance since the external finish was stucco on timber ground. In the case of Deutsche Stahlhaus, the steel framework was prefabricated into panels at the factory, each panel being about 8 ft. 0 in. high and 3 ft. 0 in. or 6 ft. 0 in. wide.

In Germany prefabricated methods of construction were used in the multi-storey flats which are a common form of housing over there. In this type of building a prefabricated steel frame was usual, built up of several small members bolted or welded together; very large sections of framing were erected on the ground before being hoisted into position in the building. Infilling was again of pumice or other lightweight pre-cast slabs.

In concrete, apart from the use of various lightweight aggregates, such as pumice, which are discussed in another section of this book, the principal contribution was the development of the "massivblock" type of building. Very large slabs of concrete, sometimes a full storey in height and up to ten or twelve feet wide, were pre-cast in elaborately equipped yards adjacent to the site and erected by huge cranes. The work of Ernst May, housing architect at Frankfurt-on-Main, is particularly interesting; he laid out complete satellites such as that at Praunheim for erection with these great concrete slabs and organised the requisite large scale handling arrangements so necessary if this type of construction is to succeed. The layout at Praunheim was such as to facilitate the use of the cranes which ran on tracks alongside the buildings; this required a simple layout in more or less straight rows. A similar construction, using even larger slabs, which were composited with an outer skin of dense concrete and a core of clinker, was used by Dr. Kepler at Amsterdam.

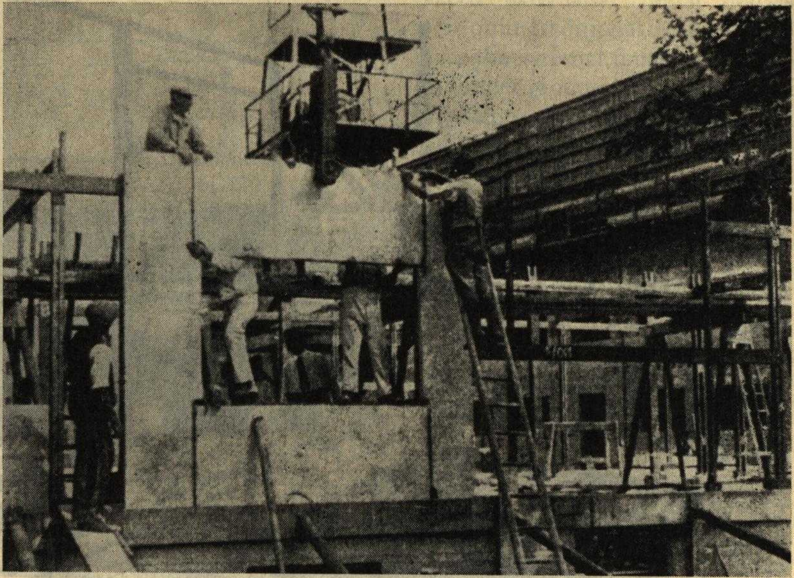
Promising as many of these developments were—and there is no doubt that they were paving the way to reduced costs in house building—they were cut short by the advent to power of the Nazis in 1933, when the use of steel for house building was prohibited and a conception of return to "Germanic" ideals supplanted the healthy progressive outlook which had held the field.



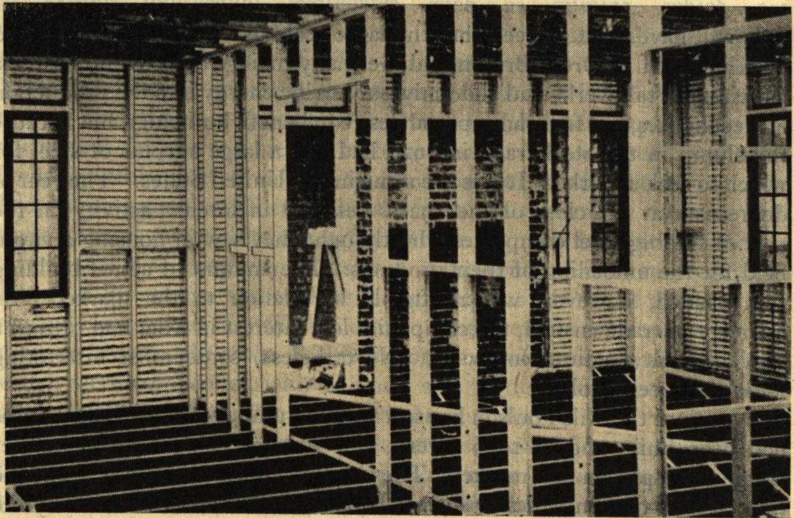
57. Deutsche Stahlhaus being erected. Note the convenient size of the frames for handling purposes. This structure could be built up to three storeys in height.

It will have been noticed that the large scale use of prefabrication had been inspired in Great Britain and Germany mainly by economic causes. Vereinigte Stahlwerke had suddenly put terrific energy into the production of steel houses, not from any special desire to benefit humanity, but because the slump in the steel trade in 1927 had left a large surplus of steel for which to seek a market. It was the same in the United States. The year of depression at the close of the 1920's resulted in intense activity on the part of the big steel companies who thought they saw in housing a virgin field for the unloading of their products. The amount of actual building that ensued, however, was negligible in relation to the market. As recovery in trade ensued, the companies lost interest in what had proved a very difficult medium for sales. Nevertheless, some most interesting ideas had been evolved.

Ever since the Nils Poulson house a limited number of steel frame houses had been built, and in 1926 several new systems using a metal lumber frame were put on the market. These frames derived directly from the timber construction which was traditional in America, as is shown by the term metal lumber. Studs were spaced at very close centres giving the house the appearance of a forest of steel. Later work used the metal more rationally, with members spaced much wider apart so as to take account

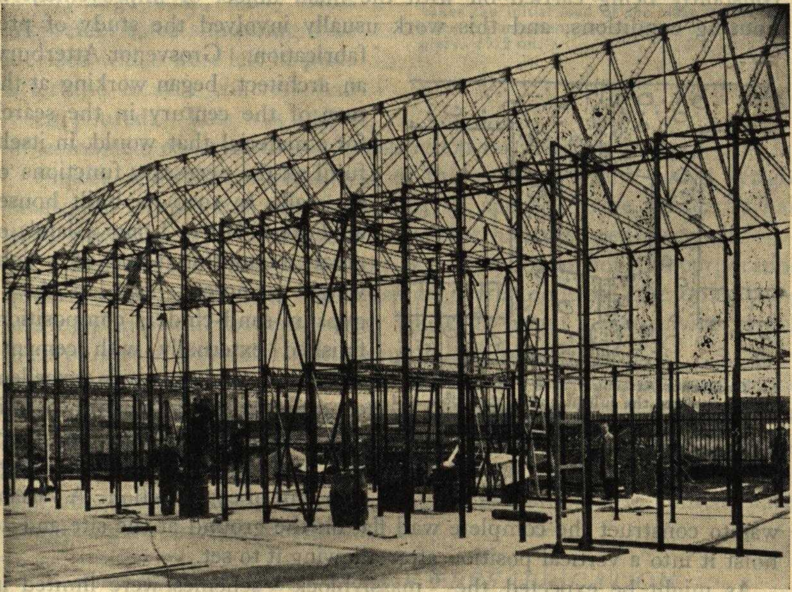


58. Katzenberger system of " massivslabs " being erected by crane. A similar system to the May system used so extensively at Frankfurt. 1927.



59. Berloy. An American " metal lumber " house which used steel as though it were wood. As in Deutsche Stahlhaus, the frame is built up into panel form in the factory before being brought onto the site. 1928.

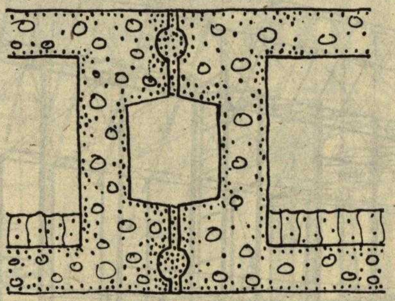
of the greater strength of steel as compared with wood. About this time a new and far reaching development took place in American practice with the introduction of cold rolled strip on a big scale and at a competitive price. This material had been developed for industries such as the manufacture of motor car bodies and it became economical for use in housing because of the presence of a mass market in other fields. It was developed in various sheet forms for floor decking and later for walling in the form of load-bearing trays, box panels or corrugated sheets. These units could be welded together at the factory to produce wall sections of very large size and relatively light weight, and the erection of the complete carcase of the house became a matter of a few hours work. Many of the frame systems also used flat or cold rolled sheet bent to suitable sections, perhaps the best known of these being Stran-Steel, introduced in 1933. Before this, a significant development in standard hot rolled sections had occurred when the Jones and Laughlin Corporation introduced their J. and L. Junior steel framed house in 1926. This firm very soon stopped marketing its house, but it has since maintained the supply of its " Junior " sections. These are lightweight rolled steel sections specially adapted for the light loading conditions obtaining in house design. We have no counterpart to these sections in this country ; in any case the normal standard



60. Hills Patent Glazing Co's " Presweld " frame. A new British system of welded lattice steel framing. 1943. See also Fig. 101.

sections are much too wasteful to be used extensively in housing. Other firms developed lattice beams to fulfil the same functions. These are beams which have slits cut in their webs and are then expanded to give a beam of great depth and light weight suitable for domestic loads. The same result is obtained by welding steel rods in a lattice framework pattern to steel flanges; this is the method now being used by the Hills Patent Glazing Company for steel frame members in this country. Extensive use was being made of these light members in the United States prior to the war and they are beginning to be introduced here.

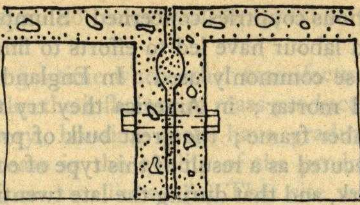
Comparison of pre-cast concrete systems in different countries is very interesting. In this country two types, concrete masonry and pier and panel systems, predominated to the virtual exclusion of other types. In Germany the pier and panel did not exist; they favoured the use of concrete in masonry types or in large monolithic slabs or in combination with a steel frame. In the United States every type was tried and experiments were carried on continuously from the beginning of the century and quite independently of fortuitous economic pressure. This is the factor that distinguished the American experiments in prefabrication from those of all other countries with the possible exception of France. In America, though commercial sponsors strained themselves as elsewhere if, and only if, they saw the possibility of gain, a nucleus of research was constantly being carried on with the main object of improvement in housing conditions, and this work usually involved the study of prefabrication. Grosvenor Atterbury, an architect, began working at the turn of the century in the search for a material that would, in itself, fulfil all the necessary functions of the wall. In 1920 he built houses at Forest Hills, Long Island, of great monolithic slabs of a light weight concrete, said to be a gypsum-sand-cinders composition, finished externally with cement; these are said to be in excellent condition at the present time. This line of thought persisted and there are many examples of the large slab type of construction. A variant was to construct the complete wall flat on the ground at the site and to hoist it into a vertical position after allowing it to set.



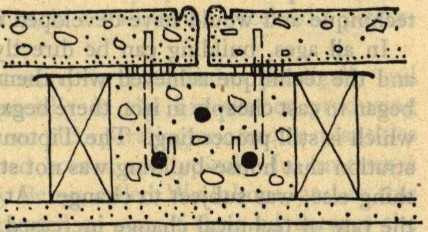
61. Grosvenor Atterbury used enormous monolithic slabs, the full height of the room and up to 10 or 12 ft. wide. They were cured and of lightweight concrete and had a layer of insulation incorporated in them. 1920.

As might be expected, the "massivblock" schemes were limited in range, requiring the establishment of a casting and curing plant near to the site and it seems somewhat illogical to try to perfect a lightweight material,

as Atterbury did, and then to nullify the advantages it possesses by casting it in great unwieldy units. One of the most successful types of unit was the U-shaped load-bearing panel of storey height, from 12 in. to 4 ft. 0 in. wide, which was set vertically to form the wall. Such units were readily handled and when erected formed the whole substance of the wall, pier and panel combined and required only internal lining. One such type, Rockwood Gypsum Lumber, was composed of gypsum in hollow beam form, the beam being tongued and grooved and set without mortar.



62. Armostone, U.S.A. Precast pan-shaped units, storey height and up to 6 ft. 0 in. wide, typical of a wide range of this type of concrete construction. 1920.



63. John J. Earley, U.S.A. Large precast slabs of dense concrete hung onto a poured in-situ R.C. frame. The timber framework which takes the initial load of the slabs is left in place as permanent shuttering to the in-situ piers. 1915 on.

Pier and panel types were plentiful, but were not used on a very large scale ; many forms of prefabricated shuttering were devised which were left in place after the in situ concrete had been poured. This was a type of combined concrete-timber construction not used over here.

Finally, the cellular frame type of the architect Frank Lloyd Wright was quite unique and was claimed by its sponsor to be lighter by half than any other type of concrete house that had yet been designed.

Just before the outbreak of war several types of house incorporating pressed steel frames with timber siding were produced, the units being made up into wall sections, storey height by about a metre wide, which incorporated rock wool insulation in quilted form.

In all this wealth of experiment hardly a single system achieved actual mass production and until the outbreak of war none except the traditional timber types had reached the figures of Weir and Dorlonco in this country. Nevertheless, the experience and aptitude was there so that during the war almost the entire defence housing programme in the United States could be given over to prefabrication.

THE MATERIALS OF PREFABRICATION

In tracing this brief history of prefabrication, I have tried to show that development has been closely bound up with economic causes in the

various countries concerned. Slumps and shortages of particular materials and labour have led to efforts to find means of building as alternatives to those commonly used. In England we try to find substitutes for bricks and mortar; in America they try to find substitutes for the traditional timber frame; the great bulk of prefabricated building to date has been executed as a result of this type of economic influence. Our own post-war work, and that during the late twenties in Germany as well as the Defence Housing in America, come within this category. We then find that, where this is so, prefabrication is regarded rather as a temporary stopgap than as an end in itself.

There have been other and more fundamental causative features at work, for prefabrication derives from improvements in materials and technique and would have developed irrespective of such emergencies.

In all ages, building can be directly related to the materials available and the technique achieved with them. When, in the early 1800's, man began to cast cheaply in iron there began a revolution in building technique which is still proceeding. The Tipton Green House was the first demonstration that house-building was not static and immutable but, like everything else, was subject to change. At the turn of the nineteenth century the rate of technical change increased rapidly and a gap began to appear between house-building as carried on by traditional means and the potentialities in building which were from year to year being disclosed.

Because of ingrained tradition in the industry the new techniques were first applied to new problems of production, such as the manufacture of motor cars, where tradition was less of an impediment, until at last the building trade was in the unenviable position of being an oasis of traditional craft workers in a world otherwise given over to the machine. It was at any rate one of the very few major industries not yet mechanised.

Industries associated with building, for instance those which supplied the materials, were often very highly mechanised. We thus had the position of material of great precision coming onto the job to be knocked about, coarsely handled and built into the structure in a rough and ready manner and in juxtaposition to other material of a completely different standard of precision. We had the position that these precise and expensive units whose manufacture had been carefully controlled in respect of dimension, temperature or humidity, were left for months in a structure that was being slapped together with the aid of liberal quantities of water and that was to take several months to dry out after completion. Small wonder that shrinkage cracks and a liberal amount of patching up and warping of timber and rust of metal were regarded as normal. An inevitable sequel to this slow process was lost time during bad weather, for the work had to be carried out exposed to the elements rain, snow, and frost, and ceased altogether during inclement weather, with enormous loss of wage earning capacity and time. One bad result of the system was the habit of engaging

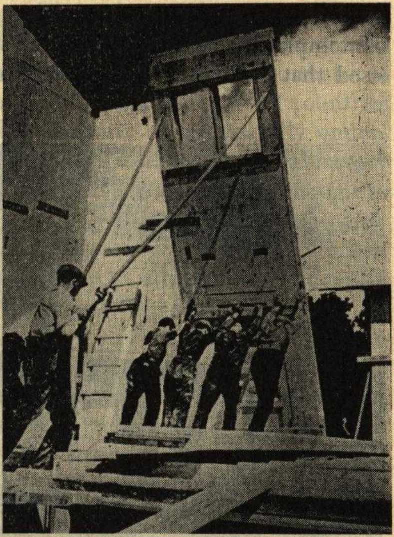
labour on day to day contracts, a system not calculated to appeal to the best type of worker.

A second point to note is that during a time when other manufactured products have come down in price under the influence of mass production and better organisation in the factory, housing costs have gradually increased without corresponding increase in the quality of the product. These facts set investigators thinking on two lines. (1) That site work must be reduced to the minimum and as far as possible be achieved with dry technique, that is by the elimination of water from the building process, and (2) that new developments of material or technique be watched to discover whether they could be adapted to housing-building.

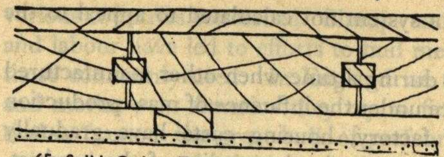
During the past decade progress in the development of materials has been enormous and prefabrication has, in consequence, received a powerful stimulus.

Only a few years ago it was customary to treat timber prodigally and many types of prefabrication, especially in the big timber producing countries, used heavy solid structures incorporating enormous quantities of wood; the Swedish prefabricated houses are typical. In America a similar type of house sponsored by Bemis called Wudnhous, and in this country the Solid Cedar houses, quoted as one of their advantages the fact that they utilised seconds and short lengths of timber that would not otherwise be usable; but, to-day, world timber consumption is probably in excess of *available* supply, if we exclude the inaccessible reserves, and we are being forced into a world-wide policy of strict conservation of lumber.

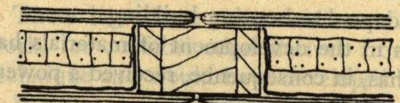
More and more, low grade timber and timber waste is being pulled apart and reconstituted as the basis of plastics and in the production of wallboards and hardboards, and waste is no longer available for these heavy types of timber construction. Timber is developing towards a more intense utilisation of its inherent properties. "Improved" or resin impregnated and compressed woods, which have the working properties of metal rather than of wood, are being developed; resin bonded plywood, more scientific methods of seasoning in the



64. A prefabricated Swedish timber house being erected largely by owner-occupier labour. The sections are formed from thick baulks of wood 2-in. thick faced externally with weather boarding.



65. Solid Cedar, Tarran Industries, Ltd., Hull. Wall formed of 2¼ in. solid cedar planking with weatherboard externally and plaster-board internally. 1938.



66. The American Forest Products resin bonded stressed skin plywood house, the first of its kind. Resin bonded plywood sheets are adhered to a timber frame and assist in taking the stresses. Compare with Fig. 65. 1935 on.

kiln, giving greater control of moisture content and consequently greater precision and stability in the finished article, all tend towards the factory fabrication of the material where the necessary control can be exercised. The newer resin bonded structures, deriving from aircraft practice, which use thin membranes of plywood stretched on a light timber frame, represent in structural type the antithesis to the Swedish houses and signalise a great advance in the conservation of the raw material.

Steel always has been a precision material and, by its nature, a factory product which does not allow for cutting on the site. Until about twenty years ago its use in building was mainly confined to the fabrication of rolled steel frames suitable for large structures. With the development of sheet steel and continuous strip and cold presses, it became possible to contemplate the large scale use of steel in housing. It should be emphasised that in 1920–26, when steel houses were built in this country with

67. A typical example of the U.S. Forest Products House.

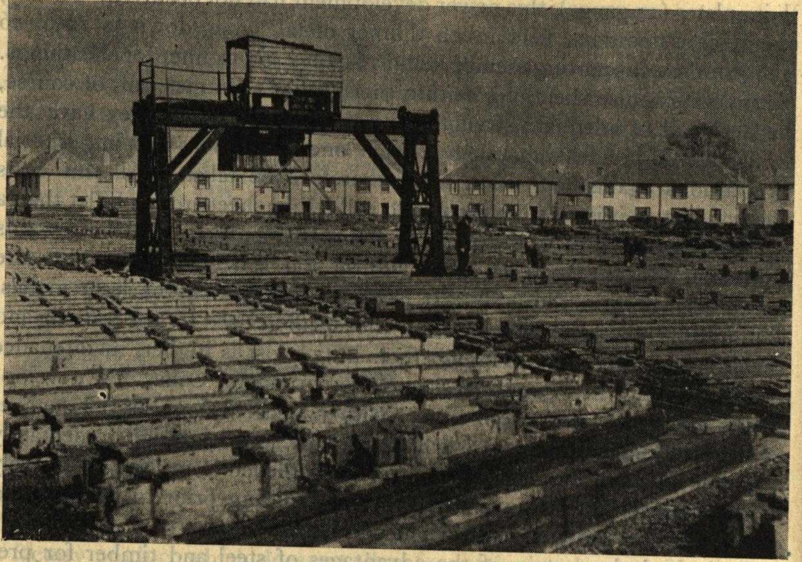
$\frac{1}{8}$-in. plates (11 gauge), this newer development had not occurred. To-day, the steel systems use very much thinner metal, going down to 12 to 16 gauge for the supporting members and 16 gauge and thinner for sheathings. Some systems use sheathing as thin as 24 gauge. Frames can, of course, be designed of adequate strength with these sections but they have the drawback of not leaving much margin once corrosion sets in; special precautions against corrosion must therefore be taken. All this costs money, just as it is more expensive to roll a thin sheet from a billet than a thick sheet and it is by no means certain that progress will be towards thinner and thinner material. This subject, too, is being discussed in more detail elsewhere in the book. It is even possible that the light metals, aluminium and magnesium and their alloys will be used for the framing and sheathing of buildings. Though their initial cost is higher, maintenance is lower due to their greater resistance to corrosion. Other new developments are in the surfacing of steel with non-corrosive material such as copper, nickel, aluminium or plastics. One new material immediately available on a substantial scale is vitreous enamelled iron, used extensively in the United States for various types of building prior to the war and obtainable in a wide range of bright permanent colours.

Concrete lacks certain of the advantages of steel and timber for prefabrication. It is heavy and bulky in relation to its cost, and it is brittle; these factors militate against its transport over long distances. Such difficulties can be reduced by site prefabrication, but a great deal of space is required for manufacture and subsequent curing, and the greater the speed of erection the more the space required for curing, so that it is a difficult material to use on congested sites. Experience in all countries has been that pre-cast concrete housing can only be successfully undertaken in conditions where plenty of space is available, where a local factory can serve the site or several sites, and where schemes are large enough to justify the big capital outlay involved.

Two of the most important inherent qualities of concrete are sacrificed in pre-casting; i.e., plasticity and continuity of structure. Frequently the result is an inert mass in place of a light, graceful, monolithic structure.

In spite of all this, a vast bulk of building has been carried out in pre-cast concrete. Concrete is, like brick, a complete walling material and it is cheap. Experiments in lightweight concretes, no-fines, pumice, foamed slag, or clinker aggregates have been extensive, especially in Germany, and more recently chemically aerated concrete has been produced in Sweden. Vibration is now an established technique, and pre-stressing has been used for pre-cast elements for house structure in Germany. All are developments towards lightening the material and towards rendering it less brittle.

It will be realised that all these developments in the available materials are not at present resulting in cheaper products. For the most part the



68. Site handling and curing the Boot Pier and Panel units. Note the amount of space occupied.

products are more versatile and cheaper to erect and widen the scope of building so that it can break new and exciting ground and be of improved quality ; but they are initially more expensive. Cost can only be brought down by the utmost mechanisation and standardisation both in the factory and on the site.

THE NEED FOR STANDARDISATION

In traditional building the units produced complete in the factory are subsequently built into the structure with the aid of a suitable matrix, brickwork. Brickwork can be cut about and adjusted here and there to accommodate the pre-finished article, but it will be apparent that this flexibility does not extend to the factory-made article itself. Such an article, once it is complete, cannot normally be cut or adjusted in any way. So long as the convenient matrix of brickwork is available, all is well, but when a series of factory-made articles are required to fit together, as in the prefabricated structure, no cutting can be tolerated and each article must be built to high standards of precision.

It follows that prefabricated units should be made to fit one with the other and be dimensioned on a common basis but, to date, this has not been the case. Instead, prefabricators have concentrated, not on producing some part of the house, but on designing a complete house so that they

could ensure that all the parts fitted together. Sometimes these designs were so specialised that only one type of house could be built to them, sometimes a degree of flexibility was achieved so that the individual unit could be used in various ways to produce several different types of house. What has never yet been achieved is that the units of one sponsor shall be interchangeable with those of another. In looking through the post-war types, this trend is seen clearly; we have the B.I.S.F. houses, the Braithwaite houses, the Unibuilt house and so on, all of which are specialised designs and the parts of which are not interchangeable one with the other, although the individual designs have some flexibility. The Local Authority or other buyer is committed to take the house, design, structure and finishes, lock stock and barrel or not at all. All the designs are set out in different dimensional grids which range from about 3 ft. 0 in. to 4 ft. 0 in. This means that most of the collateral and sheathing materials used have to be purpose-made for each design because they are all slightly different in size. This in turn implies a breakdown in standardisation of the material and means that the specialised designs themselves must be sold upon a very big scale to be economical. Naturally, only the biggest firms can attempt to design houses on this scale and of such a type.

In place of the standardisation of parts we have the standardisation of the complete house and we are in danger of achieving thereby a most inflexible system of house-building, suiting a few large concerns at the expense of the many.

The smaller firms, who cannot contemplate the production of complete factory produced houses, but who could readily produce one or more parts of the house, such as the frame, or a sheathing element such as a type of concrete slab or vitreous enamel sheeting, are at a loss to know on what basis to standardise their wares. If the manufacturer of a steel frame decides to produce it on a grid of 3 ft. 0 in. centres and a concrete slab manufacturer has already decided to standardise his slabs at 4 ft. 0 in. widths, it will be clear that the two cannot be used together. If these two manufacturers get together and decide on a common dimension then they are faced with the fact that, for instance, steel casements are not standardised on a modular basis at all and that wood casements are different sizes still, that wallboards are standardised at 3 ft. 0 in., 4 ft. 0 in. and 5 ft. 0 in. widths and asbestos sheets and steel sheets at yet other sizes. Clearly a common foundation is lacking, and just as clearly this is holding up the production of stock items for use in prefabricated types of structure other than the specialised designs of the very big firms.

Let us adopt for a moment a rather different viewpoint. Standardisation, with the complete house as the unit, implies the mass production of the whole unit before economy can be obtained. Many individual parts of the design will only occur once or twice in each house and the finished economy of the house depends upon achieving

mass production of each individual part as well as of the whole.

The design might contain, let us say, eight identical doors and eight identical door surrounds so that if 1,000 houses were built to the pattern they would need 8,000 such units. It may be that an output of eight or ten thousand identical units enabled the manufacturer to take advantage of the economies of mass production. But if the house contained a lot of special units, such as external or re-entrant angle pieces, or special plumbing ducts, or bath tubs, only one of which could be used in each house, then the production of 1,000 houses would only involve the manufacture of 1,000 each of all these parts and the same economy would not obtain. It seems likely that the specialised designs will require a minimum of 5–10,000 before the economy of mass production is achieved in the house as a whole and before variations on the one design can be contemplated. This reinforces the contention that such designs lead to inflexibility.

Now, in America, prior to the war, a great number of designs of this type were produced and some of the biggest industrial interests participated in this movement, but in no case did mass production result. The trouble was that to achieve economy the mass market was required, but was not available until the houses were cheap. Produced in hundreds only, the houses were no cheaper than other houses and they could not, therefore, break into the mass market. At £700 for each house, a firm requires a £3 or £4 million order on its books before it can go into mass production—not a job for the small firm to contemplate.

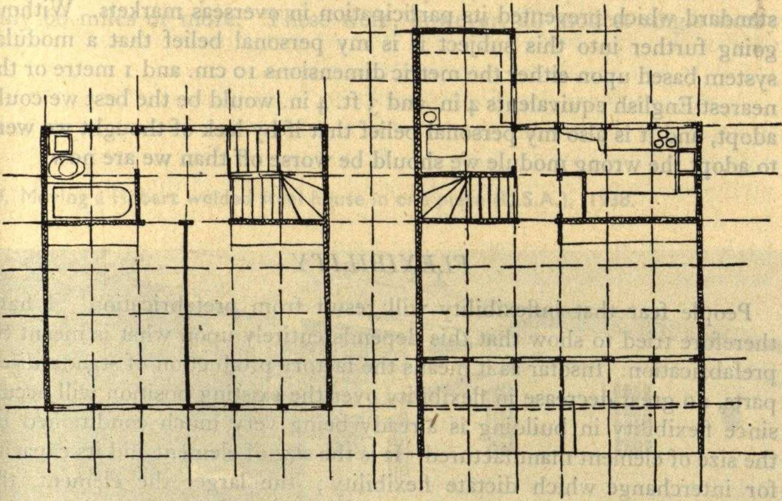
Not that 5–10,000 off is mass production as we know it to-day. Entrepreneurs tend to think rather in terms of 100,000 and we have to face the chance that the market may be collared by a few big scale producers who have broken into the market, achieved economy and gained control of the field. The alternative, equally disastrous, occurs if too many big interests try to participate in a programme too small to enable them all to mass produce on the requisite scale, for then the cost of housing will not fall and prefabrication will languish.

These remarks are occasioned because of American experience prior to the war when prefabricators were competing in a free market. The same chaos in production and frustration was evident and their actual output was small. Experience goes to show that prefabrication as at present conceived can only make its way if provided in the early stages with a protected market, such as we now have in this country after the war. But our aim must be to maintain flexibility of design and to ensure that small, as well as large, firms can participate freely in the venture of housing. For this we need to establish a common basis of dimensions to which sponsors of individual products can adhere and so that we get a range of standardised products that will fit together in different ways in the building, but, above all, that *will* fit together. This is a problem we refer to as Dimen-

sional Co-ordination, or sometimes as Modular Co-ordination, and it is not a new problem.

Ever since prefabrication became a factor to reckon with, architects and others have seen this problem looming ahead. Walter Gropius, the German architect, was one of the first to recognise it and he designed and built at the experimental Siedlung in Stuttgart in 1926 a house which was based upon a standard module of 1 metre. The real theorist of the movement, however, was Albert Farwell Bemis, an American, who originated the concept of a 4-in. cubic module, that is, one which related to heights as well as applying on plan. Bemis argued that 4 in. was the largest dimension upon which universal agreement could be obtained ; this module has achieved a considerable measure of acceptance in the United States. More recently, Gropius with Conrad Wachsman have produced in the United States a prefabricated system of building in wood based upon a cubic module of 3 ft. 4 in. which, it will be noticed, is a simple ten times multiple of 4 in. It will also be observed that 3 ft. 4 in. is a translation into English measure of the continental 1 metre (3 ft. 3½ in.) and 4 in. a translation of 10 cm. (3·937 in.).

This is not the place to indulge in detailed argument as to the appropriateness of this or that measure of standardisation—it is a technical question that must take into account suitability for planning, for the measure must satisfy the requirements of the human being. If it is too small it will result in cramped plans—a dimension of 3 ft. 0 in. is too small



69. A modular plan. Designed by Walter Gropius and Conrad Wachsman for the Packaged Buildings Corp. of America. The module or grid used is 3 ft. 4 in. 1943

as it results in corridors, stairs, etc., of the order of only 2 ft. 8 in. and lintol heights of less than 6 ft. 0 in., both of which are inadequate. If it is too large it is extravagent in space and, as it becomes larger becomes less and less flexible. These are the main factors to be considered in fixing a suitable module and, additionally, the modular system has to be such as will accommodate satisfactorily the whole range of building products that will wish to use the scale. I have heard it said that prefabricators cannot economically design to a modular scale but an examination of a few hundred types of prefabrication indicates that there is no inherent difficulty. Such difficulty as may arise is due to the predisposition of sponsors to continue manufacturing their own product on their existing basis with the hope that others will fall into line. There is no single figure that will satisfy everybody in the first instance and the establishment of a modular system implies setting up a completely new standard which, starting from scratch, will gradually gain adherents until a nucleus of materials designed upon a modular basis is attained. Thereafter, the snowball might be expected to grow at an increasing rate. On this assumption, manufacturers need not immediately retool to the new basis, but only as soon as retooling becomes necessary to keep them up to date.

Trade in the future is going to take on an increasingly international character. It is reasonable to assume that, as building products are increasingly prefabricated, and as they become more valuable weight for weight and bulk for bulk, the possibility of an international market will emerge. This must be borne in mind in any agreement to standardise dimensions. It would be suicidal if this country adopted an insular standard which prevented its participation in overseas markets. Without going further into this subject it is my personal belief that a modular system based upon either the metric dimensions 10 cm. and 1 metre or the nearest English equivalents 4 in. and 3 ft. 4 in. would be the best we could adopt, and it is also my personal belief that if by lack of thought we were to adopt the wrong module we should be worse off than we are now.

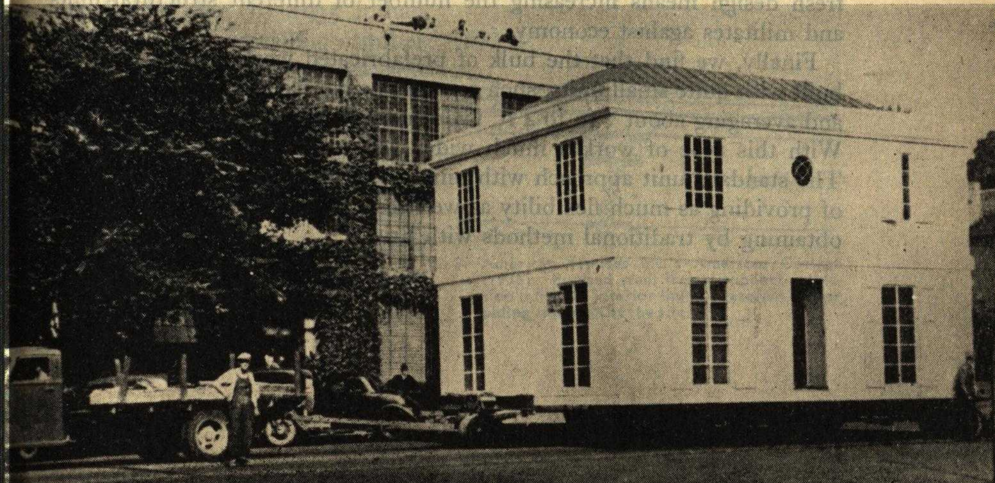
FLEXIBILITY

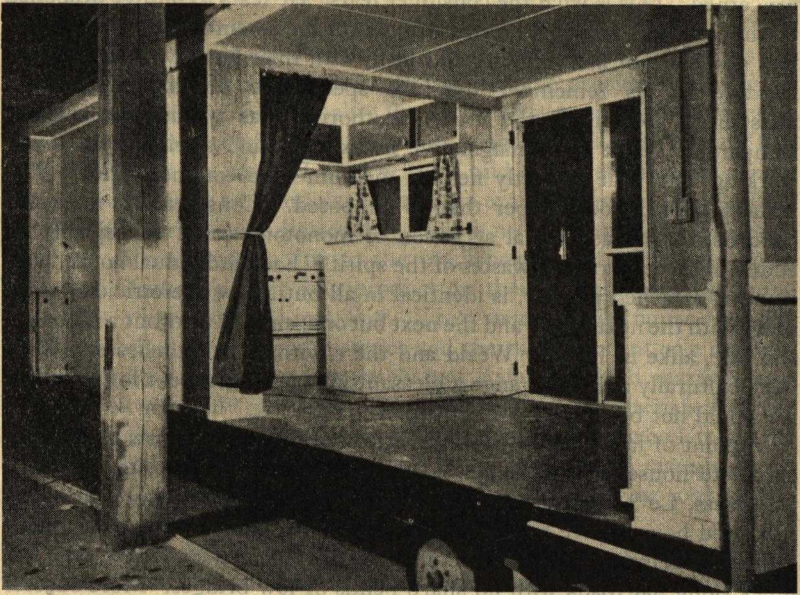
People fear that inflexibility will result from prefabrication. I have therefore tried to show that this depends entirely upon what is meant by prefabrication. Insofar as it means the factory production of standardised parts, no great decrease in flexibility over the existing position will occur, since flexibility in building is already being very much conditioned by the size of element manufactured. It is the size of element and its capacity for interchange which dictate flexibility; the larger the element, the less flexible it is. If the whole house is built in the factory and becomes the unit of sale, flexibility has ceased to exist so far as the consumer is

concerned. This is what the consumer fears. He fears a country despoiled by thousands of identical houses straight off the assembly lines which give him no choice of individuality and fit ill with their locality or site. As an antidote let us remember that the speculative builder (and, be it whispered, sometimes the Local Authority) has already achieved a comparable result of unimaginative inflexibility and sterility even when working with that perfectly flexible medium—the common brick. The malady indeed goes deeper than is supposed. Consider our inter-war suburbs. What additional accession of monotony could conceivably be added to these terrifying wastes of the spirit ? Each individual house, with its semi-detached partner, is identical in all but a few meretricious trappings with the next block, and the next but one, and the next but a thousand and one, alike in Harrow Weald and the environs of Manchester. If we were culturally able to arrange a pleasant living environment for ourselves we would not be fearing prefabrication.

In point of fact, little success has attended the many efforts to produce complete houses at the factory ready for delivery to the site. Hobart, Van Ness, Le Tourneau are three isolated cases, all from America, where full sized houses have been thus produced and then only for a very local radius of delivery. Such structures can only be transported a very few miles along flat roads with no sharp bends or low bridges. More success has been achieved by efforts to produce the house in two or more sections which require only bolting together at the site and connecting up to the drains and services. The Tennessee Valley Authority have built hundreds of houses in this way and found that they could transport them economically 60 miles or more. These were, however, all modest single storey

70. Moving a Hobart welded steel house in one piece (U.S.A.). 1938.





71. Section of a T.V.A. House ready for shipment from the factory (U.S.A.). 1939.

structures. Flexibility with this type of structure is restricted to the ability to add or subtract a complete section.

At the next stage down, whole walls are built up in the factory or cast in moulds at the site and the house is fitted together from anything from a dozen to fifty pieces. Again the flexibility of design is limited if mass production is to be achieved. In practice, systems of this type stick to a few designs on which the changes can be rung. The introduction of a fresh design means increasing the number of different structural units and militates against economy.

Finally, we find that the bulk of prefabricated work has, so far, been built with quite small units, such as could be handled by one or two men, and averaging about 3 ft. to 4 ft. wide and any height up to three storeys. With this type of work a much wider variety of treatment is possible. The standard unit approach with units based on modest sizes is capable of providing as much flexibility as we need and more than we have been obtaining by traditional methods with brick.

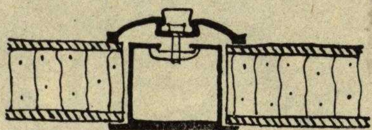
PREFABRICATION NEEDS A NEW APPROACH TO DESIGN

If you turn to the photograph of the old iron house at Tipton Green you will realise at once that here is a new type of construction that has called forth a new expression in design. Here is a genuine iron house and one that looks as though it is. So it was with the Crystal Palace, a frank expression of the repetitive methods of production employed, resulting in a work of architecture which became a subject of pilgrimage for architects all over the globe. We have suffered a recession since then.

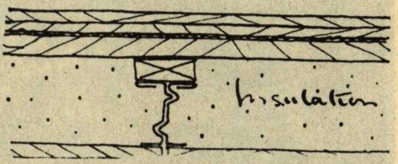
The designers of the 1920's in this country suffered from an inferiority complex and were only too conscious that their work was regarded merely as a substitute. A natural corollary of this attitude was that the prefabricated designs, whether in steel, or concrete, or cast iron, were woven around traditional plans and given, as nearly as may be, a traditional exterior. These houses were made with consummate success to look like rendered brick buildings and it is only by close investigation that the telltale scale of the steel sheets or concrete blocks reveals itself. More than that, domestic architecture in the country was at the time being cast on artificially " traditional " lines and so far as they were able, the structural innovators followed like sheep in the prevailing fashion. It was the same in other countries. By and large, the German steel house looked like a wattle and daub Bavarian cottage and the latest achievement of series production in America was dressed up as a Colonial or Cape Cod masterpiece.

This was not entirely the fault of the designer. One pioneer type, American Motohomes, with its brilliant Architect-Sponsor Robert McCaughlin was brought out in 1932. With steel sheeting, aluminium cover strip and the first commercialised kitchen-bathroom unit, this had met with so limited a response from the Great American Public that by 1935 it had developed the prevailing timber siding to cover its nakedness and was being offered in the usual immaculate historical styles.

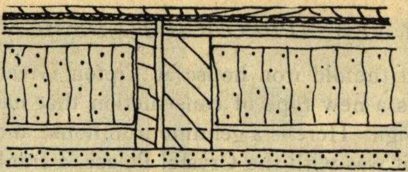
All too often no designer of competence was employed on the work and, even when a contemporary solution was sought, it was shallow and what we contemptuously refer to as " moderne."



72. American Houses Inc.'s original Motohomes (1932). A pressed steel tubular frame supports " sandwich " panels of asbestos and plywood on a core of insulating materials. They are held in place with an aluminium cover strip.



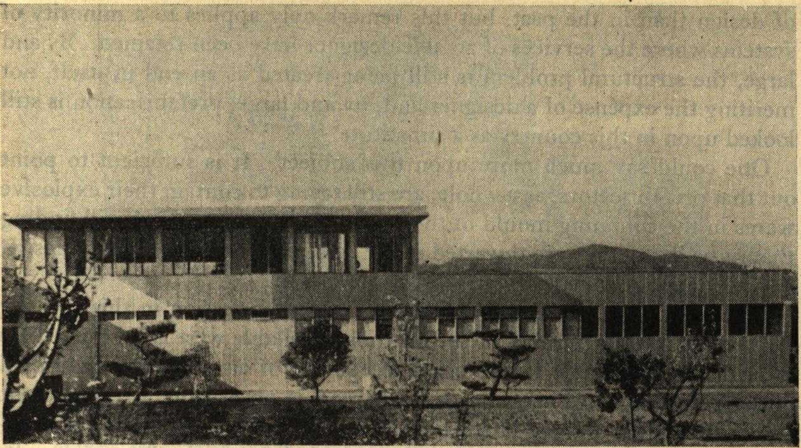
3. American Houses Inc.'s American Cottage (1936). Pressed steel frames support insulation infill and interior lining. External timber siding is put on at the site.



74. American Houses Inc.'s all timber house. Typical of a vast number of American single storey timber buildings. A timber stud frame, faced with plyboard and with insulation packed between the studs, has a timber sided exterior applied at the site. Finished internally with plasterboard or fibreboard. 1935 on.

This grim picture of failure to achieve a happy aesthetic result in the new constructional medium is relieved by the work of a few brilliant architects such as Gropius in Germany, Neutra in America and Beaudouin and Lods in France. To such men, working in the new materials, the new concepts came naturally. They understood all the implications of the new resources placed at their disposal. Neutra, particularly, took the standard products of industry, steel framing elements, Messrs. H. H. Robertson's steel floor and wall decking, or asbestos, and developed out of them a distinctive series of houses which are an object lesson in prefabricated design. Beaudouin and Lods, in collaboration with the engineer Mopin, illustrated at Drancy, near Paris, how reinforced concrete elements could be treated and, at Clichy, showed how steel and glass repetitive

75. American cottage. Apparently a bona fide traditional timber house but really one of the latest efforts of American quantity production. See also Fig. 97.



76. House in California built up of Robertson's standard pressed steel sheets. Richard Neutra, Architect.

elements could still be used in a manner by no means unworthy of comparison with the Crystal Palace.

From the published designs of some of the systems proposed for post-war use in this country we have been better served from the point of view

77. The Covered Market at Clichy, Paris, by the Architect's Beaudouin and Lods. A steel and glass building, the modern counterpart of the Crystal Palace.

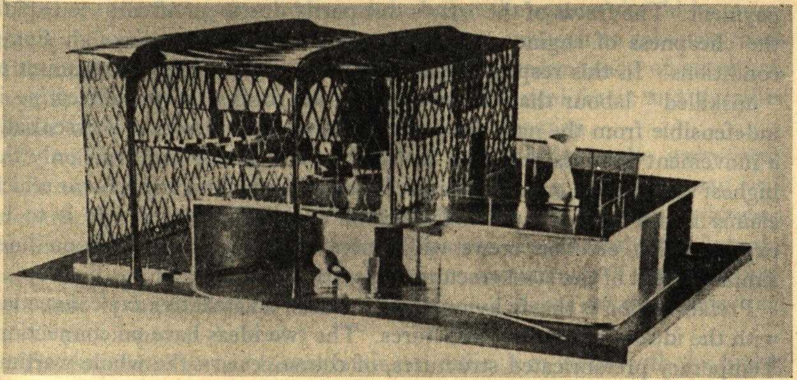
of design than in the past, but this remark only applies to a minority of systems where the services of an able designer have been retained. By and large, the structural problem is still being treated as an end in itself, not meriting the expense of a designer and, by and large, prefabrication is still looked upon in this country as a substitute.

One could say much more upon this subject. It is sufficient to point out that prefabricators, as a whole, are still trying to contain their explosive wares in the confining mould of the traditional house, and are still finding that by so doing they are thwarted in the achievement of freedom of design and economy of construction.

It was noticeable in the earlier period of prefabrication in this country that only a limited number of the solutions available were tried out. This is primarily ascribable to the prior acceptance of an arbitrary traditional outlook to design. The same general trend is observable at the present time. Published designs in steel indicate that they are all based on semi-detached houses of the same overall size and shape as the 850–950 sq. ft. municipal or speculative builder's cottage. They can be adapted to some extent to other types but this is their norm. All the steel frame systems are of the close-spaced variety with stud spacings of the order of 3 ft. 0 in. to 3 ft. 6 in. and with flexibility, such as it is, within a fixed external shell—the biological form of the crustacean. In practice, as the inter-war plans of the speculative builder teach us, such a small building allows little internal flexibility.

Contemporary architecture, on the other hand, has been moving towards the free plan based on an internal framework (like that of a vertebrate) so that the external walls of the building as well as the internal are flexible and not load-bearing. So far as I am aware, no such system is proposed in this country, despite the evident advantages from a living point of view, and I am forced to the conclusion that we are concentrating once more on one type of house and ignoring a number of possible alternative solutions to the housing problem as a whole. We are concentrating on alternative constructions but not on alternative concepts. This militates against the imaginativeness which our prefabrication could display. This country has produced no Dymaxion or Diatom or any other of the vivid suspended houses shown in model form in the States. It has instituted no basic modification of the interior fitting or economy of the house. Where is our counterpart to the original John B. Pierce prefabricated kitchen-bathroom unit produced in 1931 or to American Houses Inc's. prefabricated plumbing unit (1932)? What have we produced to equal Buckminster Fuller's four-piece copper bathroom, later elaborated into his Deployment Unit, which he conceived as a service annexe complete with kitchen, bathroom, heating unit and laundry, all produced in one unit which could be mounted on wheels for transportation to another lot if the family moved?

This constant crop of ideas emphasises the essential difference in the



78. Amusing model of house designed by Paul Nelson for the Museum of Modern Art, New York ; though not to be taken too seriously it aptly illustrates the principle of the " free " plan and the scope for new ideas in house design.

attitude to prefabrication in the United States, where it is now regarded as a normal part of the progressing economy, and in this country, where it is an exceptional stopgap, very much down on the earth. A definite problem confronts us and we are getting down to solve it. We are not looking round with curiosity to see whether it might be part of a much larger problem—the problem of living environment.

One other reason for this relative lack of initiative might be traced to the lack of adequate endowment for housing research comparable with the Russel Sage Foundation, J. B. Pierce Foundation, Bemis Laboratories or Purdue University in the States. Here there is no private body endowed to study housing and the living environment.

THE POST-WAR POSITION IN THIS COUNTRY

It is now generally recognised that prefabrication must play a leading part in our post-war housing drive. The position is that there remains a shortage of skilled building craftsmen following their traditional trades and, concurrently, a good supply of labour highly skilled in the mechanical trades. Many of the latter could be absorbed into the housing programme by means of prefabrication and the consequential use of steel, the light metals, processed woods and plastics and preformed concrete.

It is essential to clear the labour position at an early stage so as to avoid a repetition of the labour dispute that followed the last war. Two points must be realised : the Trades Unions must realise that new skills and trades *are* entering the building field and will eventually take their place alongside other skilled building craftsmen ; entrepreneurs must, on their side, recognise that the new skills are equal to the old and require equal

payment. The fracas of the 1920's was partly due to an attempt to exploit the cheapness of engineering labour which was passing through slump conditions. In this respect the current tendency to stress the amount of "unskilled" labour that can be used in the process of prefabricating is indefensible from the national point of view. Prefabrication is essentially a movement towards precision in building and in the long run only the highest skill is good enough. Suspicion should attach to any scheme which claims it can be put up "mainly with unskilled labour." It is to be expected that erection crews will evolve high degrees of skill on lines similar to that of the steel erectors of the present time.

Prefabrication is slowly living down its unfortunate latter day connection with the idea of temporary structures. The two ideas have no connection. Temporary prefabricated structures, of course, exist—the whole wartime output, both here and in America, of defence housing and hutments is of this category—but any desired standard of quality and performance can be attained by prefabricated methods, as the earlier historical sketch must have indicated. Indeed, the more accurate control that can be exercised in the factory enables the designer to fulfil many of these standards with greater precision. It is up to Local Authorities and others engaged in building to satisfy themselves that any method of building which they may be considering measures up to the minimum standards suggested in the various Government reports on housing, such as the Report of the Committee on House Construction, 1944 (usually called the Burt Report) and the Housing Manual, 1944, with its technical appendices. For this they should have the best specialist advice.

The essential requirements which a prefabricated house must fulfil throughout its useful life can be summarised as follows. That it should keep out the weather over the full period for which it is designed. If it is concrete, that it shall not fail by crazing or moisture penetration, or disintegrate due to faulty material. If steel, that it shall not corrode away.

Corrosion with the light gauge steels now being projected for use both as cladding and framing elements, is still something of a hazard as well as a problem to the designer. All steel which is enclosed must be treated either by painting or galvanising, and the protective coat is very difficult to maintain intact during erection. This problem tends to rocket the cost of light steel frames and is one reason why the light metals (aluminium and its alloys) are being considered.

The method of jointing in any system of prefabrication should be carefully looked into ; joints which are wholly satisfactory are rare. A joint has to be watertight and yet allow for any movement in the material. Capillary attraction should be guarded against and this will occur where a grouted joint has been cracked by movement in the structure as well as at more obvious places. Mastics tend to dry up and come away from the material, or they may slump ; in any case, they require periodic attention.

Perhaps the first point to have made is that the system should be structurally adequate. This will assume adequate strength to take the loads without undue deflection and whilst avoiding redundancy of structure, such as the provision in the same building of a steel frame and a timber frame, each in itself adequate for the loads in question.

It will have adequate fire resistance, particularly at the party wall. Definite standards of fire resistance are laid down and the party wall construction is frequently a weakness of schemes. Steel framed structures, for instance, in which the framework passes continuously through the party wall are liable to fail in this respect, particularly if the party wall structure is supported on the frames, since collapse of the frame then involves collapse of the wall.

The requisite thermal insulation is not difficult to attain with the highly efficient materials now on the market. In concrete work, cavity walling and a lightweight slab inner leaf or a sufficient thickness of solid wall of lightweight concrete, rendered, can be made adequate, and in timber or steel, the insertion of blanket or loose pack insulation or fibreboards and so on can give a very efficient wall which is at the same time extremely thin. Such walls are produced as little as two or three inches in thickness.

One problem which is much more difficult to solve is that of sound insulation, dealt with in more detail in another part of this volume. Unfortunately, the lighter the structure the less satisfactory it becomes from the sound standpoint, and only methods of carefully segregated and discontinuous types of construction are likely to prove effective. It is not possible to dogmatise succintly on methods of sound reduction as every scheme must be treated on its merits and, once more, expert advice should be sought.

This brief resumé of the subject will have served its purpose if it has indicated that here is a movement that is, whether we like it or not, revitalising the whole building field in all countries. Mistakes are being made. Too many people are pushing ahead with new ideas that have no backing in research and are predestined to failure. Too often, the problem is approached purely as one of construction with lamentable results to the appearance and design-efficiency of the building. Too much attention is being devoted to securing patents and specialised pieces of design instead of to the solution of the housing problem. Too many sponsors are pushing a material of their own make under the guise of systems of building. Too many Local Authorities are thinking purely in terms of the numbers of houses they can put up rather than seeing the whole equation : numbers—quality—pleasantness. Too few designers of calibre are engaged at the right level in the production of prefabricated types. There is all too little independent objective thinking.

It would be rash, with this background, to forecast an easy housing millennium in the near future. We shall have to wait for less harassed

times before we can really sit back to plan our lives on the saner and more wholesome scale envisaged by Mumford, where the obsession with quantity has been overcome and qualitative values have taken prior place.

For further reading in this subject reference should be made to the bibliographies issued by the Libraries of the Royal Institute of British Architects and the Building Research Station at Garston, Herts.

SECTION V

THE STEEL-FRAMED HOUSE

WHEREAS the last Paper was principally concerned with providing the general background against which the rapid extension of methods of prefabrication is taking place, this contribution approaches the problem of achieving a scientific house design from a directly practical point of view.

It is arguable that limits may have to be set to the universal adoption of prefabrication, insofar as that implies the standardisation of house types and imposes a quite unnecessary rigidity on design. It appears rather that houses should be designed to satisfy exacting performance standards, making full use of the freedom in design provided by the light steel frame.

In this country, the steel frame has become the normal structural system for large blocks of offices and flats. The same material, though using a totally different technique, is now ready for large-scale adoption in the case of the ordinary small house. For this purpose, light steel framings at close spacings are to take the place of the heavy beams and stanchions with which we are familiar.

The initial fabrication of the steel members will take place before they are brought on to the site. It is of course possible to build up fairly large members in the shop, but this complicates the problems of transport and there are not always compensating advantages.

On this framework, the full range of cladding materials can be used. These no longer have any main structural function to perform and may therefore be chosen for their suitability from the point of view of sound, heat and weatherproofing, of maintenance and of appearance.

Mr. Donovan H. Lee, author of the following Paper, is Consulting Engineer to the British Iron and Steel Federation. Those who did not see the B.I.S.F. prototypes at Northolt will be able to gauge from the illustrations in this book how attractive houses designed on these principles can be.

THE STEEL-FRAMED HOUSE

By DONOVAN H. LEE, B.SC., M.INST.C.E., M.I.STRUCT.E.

WHILE steel-framed houses would, at the present time, warrant favour merely as a means of substantially increasing the number of houses which can be built to help solve the immediate shortage, it is arguable that the time has now arrived when house construction is changing for good. It appears likely that the effects of the mass production of standard frameworks and new types of built-in components may be more far-reaching and more conclusive than is now generally recognised.

ADVANTAGES OF A FRAMEWORK

The primary justification for a framework is that it allows the use of comparatively light external and internal linings to the external walls. This facilitates quick construction. Secondly, the framework serves to locate and provide fixings for components, such as windows, doors, space heaters and plumbing units, which also further reduces site work.

79. British Iron and Steel Federation, House types A and B.

Thirdly, a framework enables the roof to be completed before the internal construction is commenced ; while this is not so important in the case of wet construction, it is almost essential with prefabricated internal construction.

It is a common fallacy that steel-framed construction should be associated mainly with prefabrication ; until the last few years, steel frames have been used almost solely in association with wet construction generally in the construction of high buildings and factories, and the extension of their use in any form for house-building is a more recent development.

It is important also to appreciate that for houses the steel framework need not differ materially as between wet internal construction and dry or prefabricated internal construction. Through its ability to withstand stresses for which it is not specifically designed (such as those due to settlement and subsidence), the steel frame has advantages over brick load-bearing construction ; the latter, with its comparative inability to withstand tensile forces and heavy shear stresses, is somewhat susceptible to foundation failures.

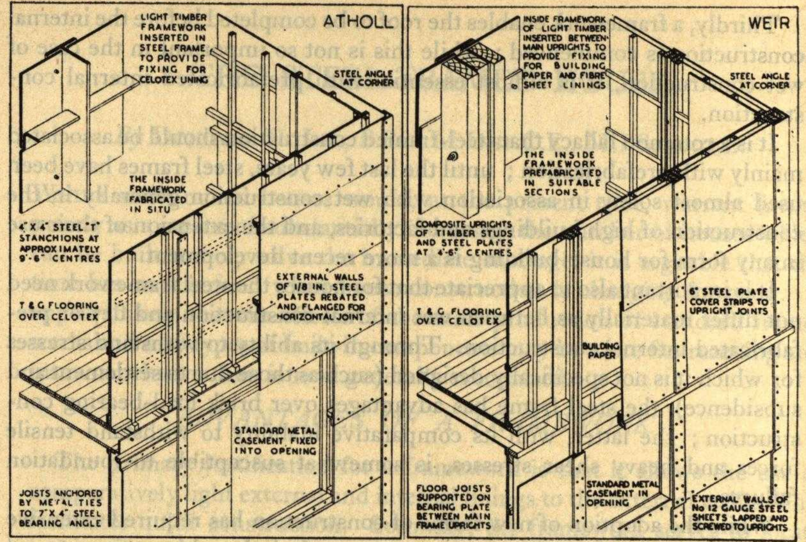
While the adoption of new forms of construction has required extensive thought and experiment to overcome new technical problems, it must not be overlooked that these forms can eliminate long-standing deficiencies in traditional construction. For example, the absorption of moisture by brickwork in wet weather, which results in chilliness in the house and requires extra heating to dry it out, is avoided by using a sheet metal external covering. Because of its absolute weather tightness, this prevents the house from becoming damp when unoccupied, and because of its low specific heat, for a given total thermal insulation it absorbs noticeably less heat in warming up.

EFFECT OF THE WAR ON DESIGN

The design of steel-framed houses is directly influenced by the relative costs and availability of the other building materials which can be used in conjunction with the steel. After the last war there was a shortage of bricks while there was plenty of timber ; there was also at one time an ample supply of thin steel plates. Types designed under the influence of the supply position of that date are shown in Fig. 80. One of these has been developed much farther since that date.

The present war, on the other hand, has produced an extreme shortage of timber ; moreover exchange conditions in the future may be expected to discourage the use of timber.

Although the timber supplies in the world are tremendous, they are not unlimited ; even if we wished to double or treble our pre-war rate of import to satisfy the needs of an expanded building programme, this demand would probably exceed the supplies at first available. Accordingly,



80. Typical steel-clad house constructions used after last war. See also Figs. 50 and 51.

timber is used sparingly in designs for framed houses. Timber in limited quantities can be used more effectively in conjunction with steel framing than is the case with the use of either material separately.

It can be assumed that there is not likely to be an irremediable shortage of bricks, cement or other home-produced materials, but as the rate of output of houses may well be several times that of the immediate pre-war period, a very definite shortage of skilled craftsmen can be anticipated.

These considerations have provoked various new forms of house construction, designed to avoid those materials which may be in short supply and to adopt prefabrication for other materials whose use will be extended. This policy aims at achieving three results at the same time ; less use of materials in short supply, more use of factory labour and less site (or building trades) labour.

METHODS OF FRAMING

The choice of the most suitable method of framing a house largely depends on the construction and finishes of the walls, floors and roof. For example, one type of semi-detached house built after the last war consisted of a steel framework which provided stanchions at six points only ; i.e. at the corners and at the end of each party wall. The roof and first floor were supported by steel beams spanning between these few stanchions.

In this case, the only advantage of the framework was to enable the roof to be completed before commencing the interior, and the other more important advantages of a framework were lost. With wide post spacing, the wall construction has to span as a panel vertically and horizontally; to do this requires nearly the same wall construction as would be needed to support the dead weight which the frame was designed to take.

In contrast, the tendency of recent years has been to provide the framing members at sufficiently close centres to enable the linings and coverings to be light and quickly fixed. In the case of wet construction the external wall cladding can be considerably reduced in thickness by taking advantage of the frequent lateral supports provided by fairly closely spaced steel posts.

Once the approximate nature of the coverings has been decided it is possible to determine a suitable spacing of members, by consideration of the costs and properties of alternative linings and covering materials and the maximum practical spacings of their supports. This applies equally to floor joists, wall posts or rafters.

The foregoing paragraphs outline the method of approach to the choice of the type of framing. The next decision is whether to design a framework to suit the particular plan and to introduce local modifications to avoid obstructions such as flues, stair well, plumbing units or other irregularities in the loading or outline, or whether to design a method of framing based on standard units with a constant width, or module, which may be used to give various sizes of house or plan arrangement. In this latter method the standardised components of the framework are used in varying arrangements for variations in plan.

It is upon this module system that a number of new types of construction are based. However, although it is easy in practice to devise a module system of framing, there is often some loss of efficiency in achieving the necessary adaptability; further, there may be some difficulty in planning the most effective use of the enclosed space without departing in one way or another from strict adherence to the module basis.

It is therefore impossible to state in advance which system is the better; even after analysis of the advantages of manufacture to be obtained by some degree of standardisation, it is necessary to take into account the economy which might result from each particular type of house being purpose-made to the most efficient individual arrangement of framing possible. Another factor that cannot be fully taken into account in advance is the possibility that small changes in planning might be desired after production had commenced or even between the fabrication of the framework and its erection. In this connection it should be recognised that although prefabrication allows variations either between components or between whole parts of houses, variations introduced during fabrication are almost bound to lead both to trouble and to extra cost; it is seldom possible to effect one change without making many others.

While the possibilities of mass production of steel components for domestic houses are not yet known, in the writer's opinion it is already evident that the benefits of prefabrication and the greater use of steel components are quickly lost by the introduction of variations.

COST VERSUS SPEED

Much has been made of the advantages of steel construction in facilitating speed in erection ; this has been given undue importance in claims made for various particular methods of construction, whether they be of steel or of other materials. Strictly speaking, special speed in constructing the framework is of small material consequence since the actual time of frame construction in any case represents but a small fraction of the time required to construct the whole house, including foundations and internal decoration. For example, the complete steel framework of the pair of houses shown in Fig. 79 takes only eight hours to erect without any mechanical aids, whereas the minimum time required under normal conditions to complete the house from foundations to finish of painting is of the order of three weeks, or even more with some types of internal construction.

It is the site hours of building labour that are the vital elements at the present time, and it is the framework which enables a large part of the traditional building work to be replaced by lighter constructions requiring less site work.

COVERINGS AND PREFABRICATION

Elsewhere in this volume Mr. Dex Harrison has dealt with prefabrication ; here it is only necessary to give consideration to the relationships that must exist between coverings and the framework.

For external coverings the requirements are protection from the weather, strength for both normal and accidental loading, rigidity, resistance to heat losses, sound-insulation, durability and low maintenance.

The strength of the external covering is directly related to the spacing of the supporting steel posts ; taking all considerations into account it will normally be found that a post is best provided at each module centre, i.e. from 3′ 0″ to 4′ 0¼″ according to the particular system used. This means that in order to meet the requirements listed above, most external coverings will need to be stiffened by cross rails or battens.

Thermal insulation need not necessarily be incorporated in the outer leaf of a cavity wall, but in the case of the roof covering some resistance to the transmission of heat is most desirable ; this should preferably be provided immediately underneath the covering. Condensation in the loft space must be prevented by insulation ; a vapour seal is sometimes added, in order to prevent the transmission of moist air.

Few materials possess in themselves all the required properties to a sufficient degree, particularly when cost is taken into account ; for this

reason, coverings used with frame construction are frequently formed of one or more different materials, which together fulfil the requirements up to any standard that may be desired. The standard adopted is very often higher than that provided by traditional methods of construction.

With the cost and performance of traditional construction as a basis, the choice of combinations of covering and lining materials now available gives scope for considerable variety in design; in the immediate post-war programme of construction, this variety will also avoid dependence upon any particular materials that might, for the time being, be in short supply.

The principal problem with the cladding of the framework, whether external or internal, for the roof, for walls, or for the floor, is how to obtain efficient fastenings which can be applied with a minimum of site labour and how to arrange these methods of attachment in such a way that they do not detract from the weather-tightness, durability, or appearance of the finished construction.

With regard to the latter, it is preferable that the external covering should be applied first; this makes it possible sometimes to render the attachments invisible from the outside, since there is access from the inside.

In this case the difficulty is to obtain a satisfactory fixing for the internal lining of the walls without access from the outside and neither to show inside fixings which detract from the finished appearance nor, as in the case of prefabricated construction, to be obliged to apply a subsequent covering finish of plaster or cover strips over the joints.

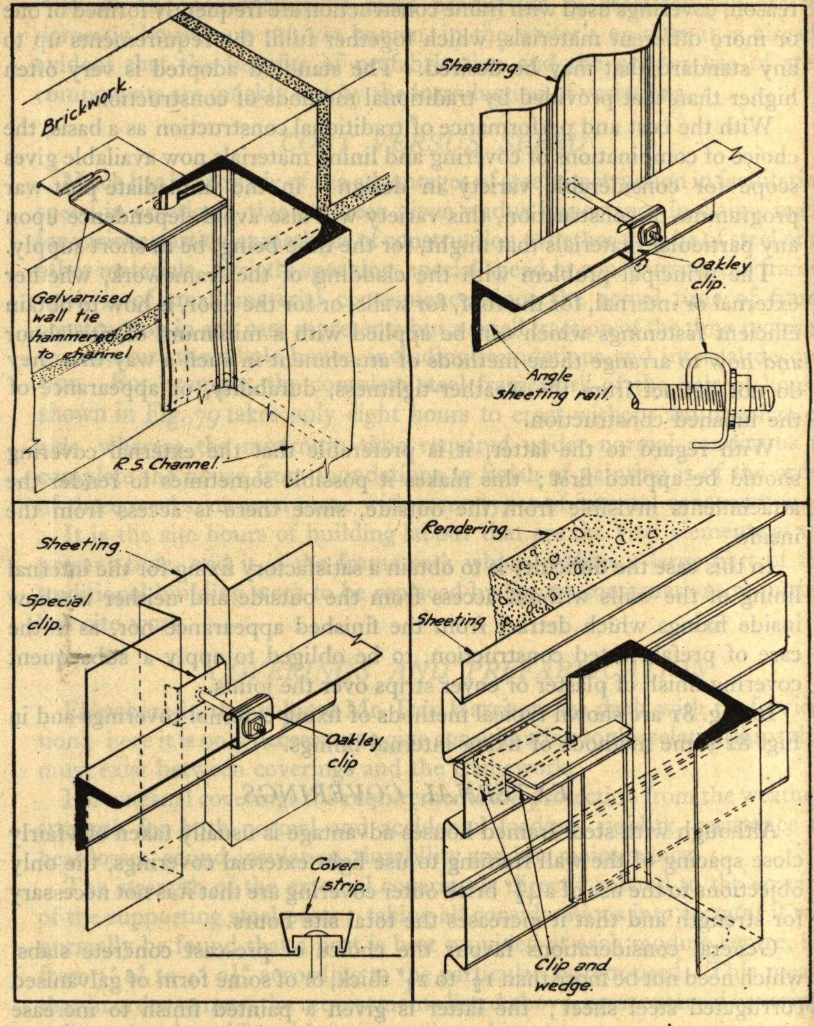
In Fig. 81 are shown typical methods of fixing external coverings and in Fig. 82 some methods of fixing internal linings.

EXTERNAL COVERINGS

Although with steel-framed houses advantage is usually taken of a fairly close spacing of the wall framing to use light external coverings, the only objections to the use of a 4½″ brick outer covering are that it is not necessary for strength and that it increases the total site hours.

General considerations favour the choice of pre-cast concrete slabs, which need not be more than 1½″ to 2½″ thick, or of some form of galvanised corrugated steel sheet; the latter is given a painted finish to increase durability and to provide a pleasant coloured external appearance.

If flat steel sheets are used, stiffeners may be spot-welded to the sheet before or after galvanising, or rust-proofed steel sheets may be used; having regard to the very low maintenance costs on the steel houses built after the last war with steel sheets treated only with paint harling, this form of finish, which is described later in this Section (see page 173), is likely to have increased use in the future. Asbestos cement corrugated sheets are an obvious alternative to steel external sheeting, above levels at which accidental blows might occur.



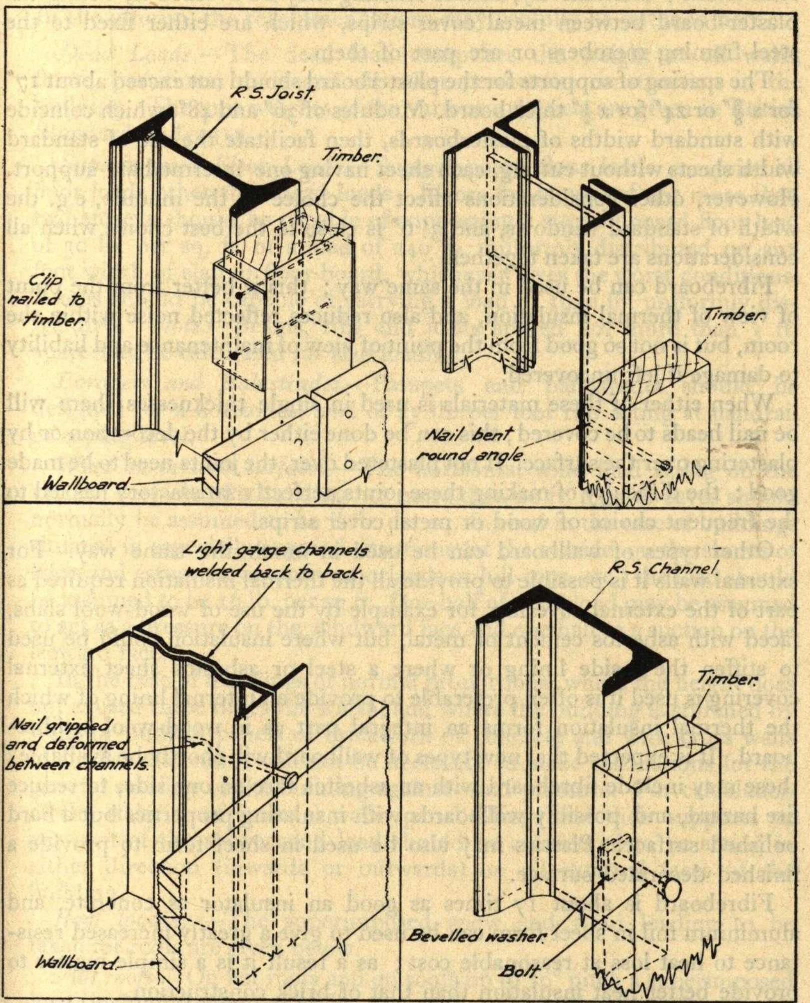
81. Methods of attaching external cladding to steel framework.

With steel posts at module centres an alternative external finish is cement rendering on some form of ribbed expanded metal or dovetail steel sheeting. Protection against corrosion should be obtained in the former case by back rendering the expanded metal and in the latter case by using galvanised steel sheets.

The advantages of steel external coverings lie, however, in the absolute watertightness of the covering and also, by a recent development of the

British Iron and Steel Federation, in the use of secret fixings whereby no fastenings show on the exposed face.

Among the many other types of external covering of which space does not allow description, one method deserves mention ; in this case flat asbestos sheets with a very finely corrugated outside surface are attached to the framework by cover strips at each module joint, the cover strip being fixed from the inside and no holes or fastenings piercing the asbestos sheet.



82. Methods of attaching internal wall linings to steel framework.

INTERNAL LININGS AND PARTITIONS

The only objection to the use of wet internal construction, for the lining of the external walls and for the partitions, is that it forfeits the opportunity the framework gives for prefabricated construction. For temporary houses where some economical, light and readily fixed lining is essential, a single thickness of plasterboard may be nailed to wood strips fastened to the steel frame ; alternatively, timber framing may be avoided by fitting the plaster-board between metal cover strips, which are either fixed to the steel-framing members or are part of them.

The spacing of supports for the plasterboard should not exceed about 17″ for a $\frac{3}{8}$″ or 24″ for a $\frac{1}{2}$″ thick board. Modules of 36″ and 48″, which coincide with standard widths of plasterboards, then facilitate the use of standard width sheets without cutting, each sheet having one intermediate support. However, other considerations affect the choice of the module, e.g. the width of standard windows, and 3′ 6″ is close to the best choice when all considerations are taken together.

Fibreboard can be used in the same way ; this is better from the point of view of thermal insulation, and also reduces reflected noise within the room, but is not so good from the point of view of maintenance and liability to damage if left uncovered.

When either of these materials is used in single thicknesses there will be nail heads to be covered; this can be done either by the decoration or by plastering over the surface. If not plastered over, the joints need to be made good ; the difficulty of making these joints perfectly satisfactory has led to the frequent choice of wood or metal cover strips.

Other types of wallboard can be used in much the same way. For external walls it is possible to provide all the thermal insulation required as part of the external covering, for example by the use of wood-wool slabs, faced with asbestos cement or metal, but where insulation could be used to stiffen the inside lining or where a steel or asbestos sheet external covering is used it is often preferable to provide an internal lining of which the thermal insulation forms an integral part as in wood-wool or fibreboard. It is expected that new types of wallboard will shortly be available ; these may include fibreboard with an asbestos face on one side, to reduce fire hazard, and possibly wallboards with insulating properties but a hard polished surface. Plastics may also be used in sheet form to provide a finished decorated surface.

Fibreboard is about 17 times as good an insulator as concrete, and aluminium foil in sheet form can be used to give a greatly increased resistance to heat loss at reasonable cost ; as a result it is a simple matter to provide better heat insulation than that of brick construction.

DESIGN OF THE FRAMEWORK

The requirements for strength and stability for dwellings have been under consideration by the Codes of Practice Committee for Civil Engineering, Public Works, Building and Construction Work. Following recommendations as to the assumptions to be made in the design of frameworks, it may be expected that a standard of minimum requirements for strength and stability will be adopted in the immediate future.

In the interim, the recommendations may usefully be outlined here ;

Dead Loads.—The dead load comprises the weight of all walls, floors, partitions, roofs and all other permanent construction in the building. The unit weights of the various materials are given in British Standard 648–1935.

Superimposed Floor Loads.—Superimposed floor loads comprise all floor loads other than dead loads. Floors for houses of not more than two storeys should be capable of supporting a superimposed floor load of 30 lb. per sq. ft. or a load of 240 lb. uniformly distributed on any foot width of slab or floor board, whichever gives the worst conditions. Beams should be capable of carrying a load of 1920 lb. uniformly distributed. *Note.*—Beams, ribs and joists spaced not more than 3 ft. apart may be calculated for slab loading.

Parapets and Balustrades.—Parapets and balustrades should be designed for a horizontal load of 25 lb. per foot run acting at handrail or coping level.

Wind on vertical surfaces.—The horizontal wind load acting on the vertical surfaces of a building not more than 20 ft. high to eaves should normally be assumed to be 8 lb. per sq. ft., but in the case of buildings situated in especially exposed situations (at the seaside, on the shores of lakes and estuaries, on open moorlands or hill-tops, etc.) the load should be assumed to be 16 lb. per sq ft. One half of wind load may be assumed to act as a pressure on the windward face and one half as a suction on the leeward face.

In the case of dwellings of normal proportions, where the height does not exceed three times the width, and where the building is stiffened by walls or built-in panels of brickwork or concrete and with cross walls of similar material it will not be necessary to make calculations for the general stability of the building against wind pressure. For calculation of the stability of external walls, panel fillings and their supports 70 per cent of the above wind load should be considered to be acting in either direction (inwards or outwards) on all external faces of the building.

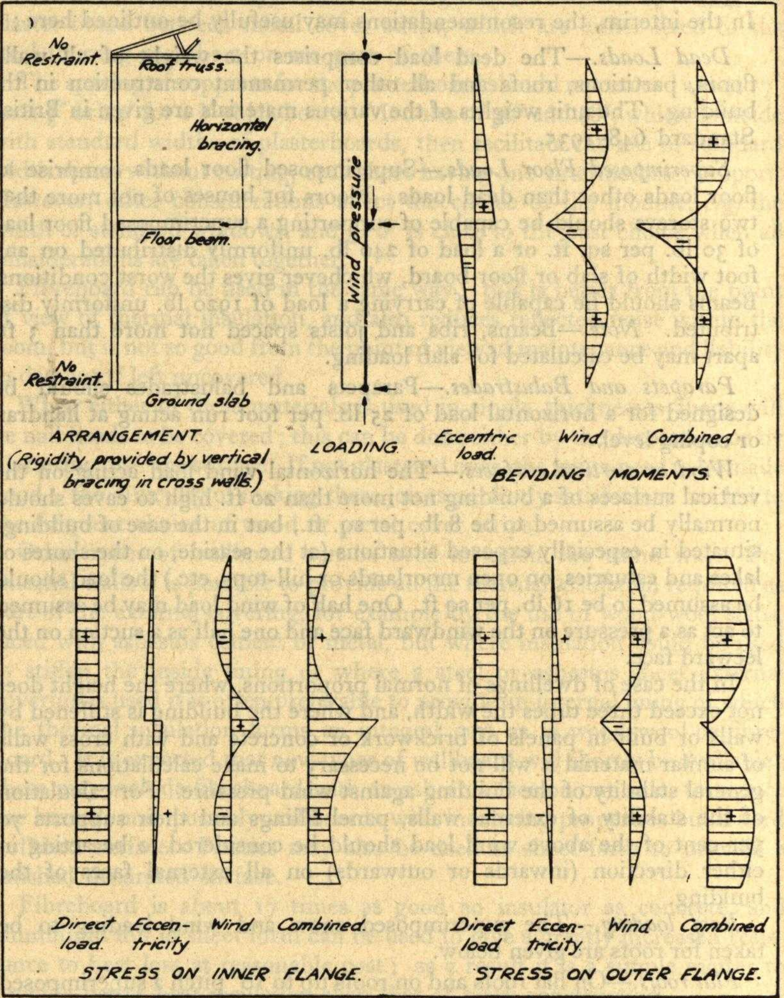
Roof loading.—The superimposed snow and wind loading to be taken for roofs are given below.

Flat roofs.—On flat roofs and on roofs up to 10° pitch a superimposed load (including snow) of 30 lb. per sq. ft. measured on plan. In the case of flat roofs of light construction, which may be affected by suction, a

negative pressure (suction) of 10 lb. per sq. ft. should be assumed to act over the whole area of the roof.

Sloping roofs.—

1. A snow load of 10 lb. per sq. ft. measured on plan.
2. A negative pressure (suction) on the leeward slope of 8 or 16 lb. per sq. ft. normal to surface. (See first paragraph of "Wind on vertical surfaces.")



83. Bending moments in posts of steel framework.

Sloping roofs should be capable of resisting the above conditions 1 and 2 singly, or in conjunction.

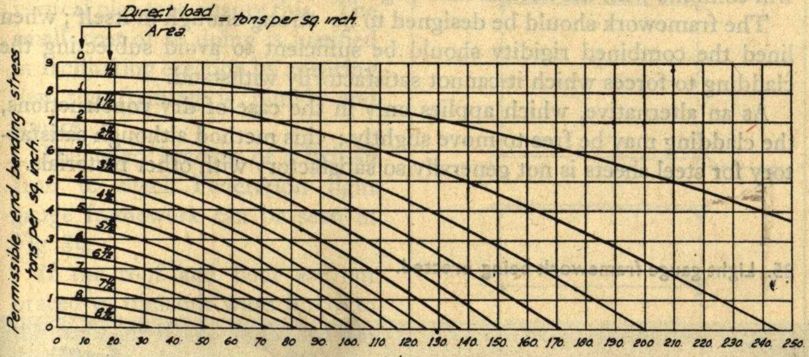
The roof covering, if it can be walked on, and the individual members of the roof framing, should be capable of sustaining the following alternative loads :

100 lb. concentrated at any point accessible by means of a ladder.

200 lb. concentrated at any point accessible without a ladder.

(The above is an extract from Post-War Building Studies No. 1, *House Construction*, by permission of H.M. Stationery Office.)

These recommendations do not prescribe the maximum permissible stresses in the steel ; these were considered by the Steel Structures Research Committee* whose provisional recommendations are incorporated in B.S.449. As some of the posts may be subjected more to bending stress than to axial compression (as may be seen from Fig. 83), the Perry-Robertson formula should preferably be replaced by the type of formula referred to in the Final Report of the Steel Structures Research Committee and shown by the graph, Fig. 84.



84. Graph for determining maximum permissible combination of direct stress and bending stress in steel posts.

With a framework of hot rolled sections it costs little more to meet the requirements of wind pressure in especially exposed situations as compared with normal exposure, but some other forms of framework become definitely more expensive under these circumstances. There is, in practice, some difficulty in deciding whether particular situations are especially exposed or not. It is doubtful, however, if more than a small fraction of likely building sites warrant provision for exceptional exposure.

There is also some doubt whether it is necessary to design for both alternative loadings on sloping roofs ; i.e. for the snow load of 10 lbs. per sq. ft. over the whole area, as well as for the suction on the leeward slope.

* The First, Second and Final Reports of the Steel Structures Research Committee were published by H.M.S.O. in 1931, 1934, and 1936 respectively.

If the wind were sufficient to produce that suction the snow would be unlikely to remain. It would seem desirable to introduce a simplification by deleting the words "or in conjunction." In the writer's opinion, it is most desirable that the requirement of alternative point loads on roof covering should be adopted in order to reduce the accidents which have occurred in recent years with the lighter and more brittle coverings; in addition it should be made clear that this requirement applies to the tops of porches and, if there might be any doubt about it, also to the roofs of outbuildings.

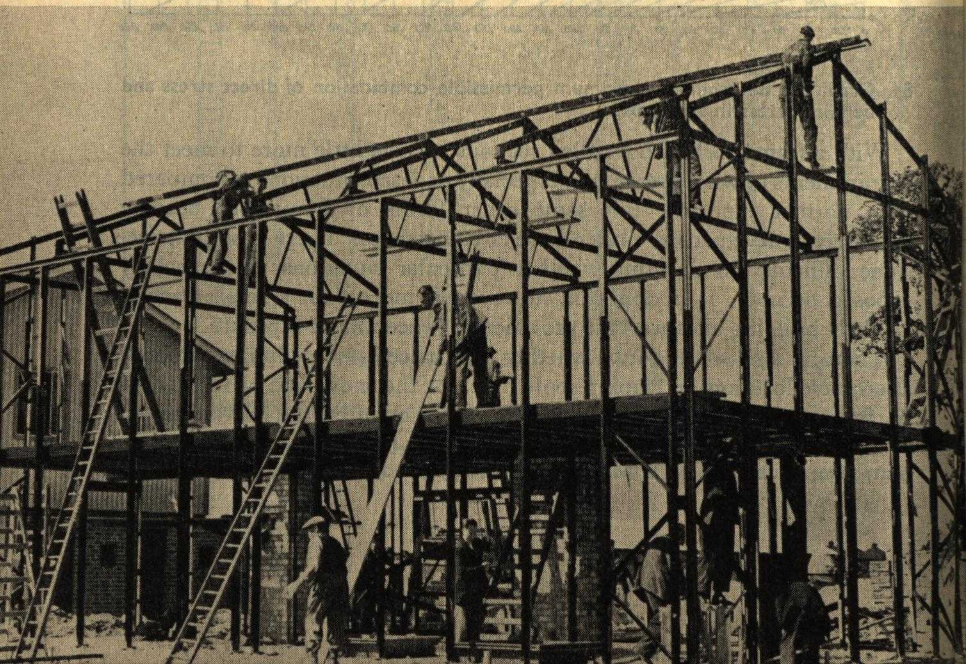
These requirements do not stipulate what stiffness a framework should have, and it must not be overlooked that some lighter forms of cladding will not be satisfactory if the framework is at all flexible. The framework itself should be reasonably stiff so that relative movements, in windy weather for example, will not produce noises or over-stress the attachments of coverings where they participate in secondary stresses.

With linings using mortar or plaster joints, any flexibility of the framing will combine with the normal shrinkage of these materials to create cracks.

The framework should be designed to be strong enough in itself; when lined the combined rigidity should be sufficient to avoid subjecting the cladding to forces which it cannot satisfactorily withstand.

As an alternative, which applies only in the case of dry constructions, the cladding may be free to move slightly; this method although satisfactory for steel sheets is not generally so satisfactory with other materials.

85. Light gauge framework being erected.



The cladding adds materially to the stiffness and stability of the whole construction.

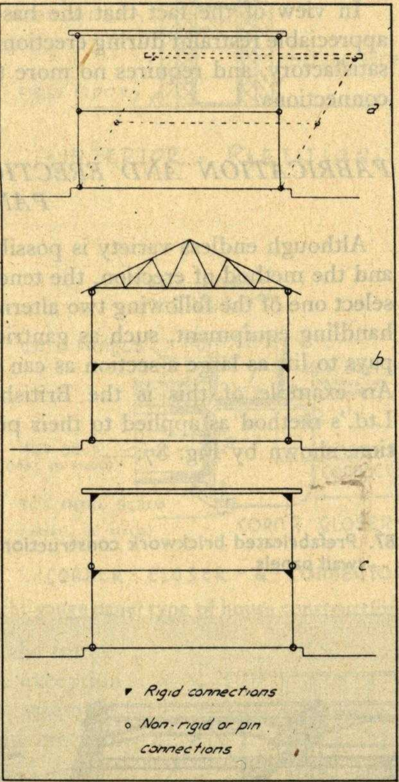
Lateral stability of a house may be obtained by using the first floor and loft floor as horizontal diaphragms which transfer wind forces on the front and back walls to the end walls and party walls ; alternatively, each bent may be made stable enough itself to resist transverse wind loads.

Generally speaking, whichever way it is designed loads will be transmitted by the floor framing ; for this reason it is best to ensure that they can do so without overstressing any parts of the framing or building finishes.

During erection, that is before the floor and roof are completed, it must also be stable, and the design should incorporate wind bracing in both horizontal and vertical planes to ensure this. The small cost of so doing is justified in facilitating erection by ensuring that the framing is plumb and square.

The wind bracing of a British Iron & Steel Federation light gauge framework can be seen in Fig. 85.

If the roof and floor are not braced to transmit wind forces to the walls, or if the walls are not braced or sufficiently stiff, the transverse bents must be stable on their own ; in this case the connections must ensure that lateral forces are taken up in producing changes in length or slope of main members of the transverse frames or bents.



86. Alternative methods of framing.
(a) Defective in transverse stability.
(b) Satisfactory in conjunction with braced or stiff end walls.
(c) Structurally stable but not often used owing to difficult erection.

As it is usually difficult to obtain complete fixity in a stanchion base fastening which would enable it to take the wind moment, the base is often assumed to act as a free hinge and stability is ensured by other and more effective means.

For example, the bent shown in Fig. 86a is unstable against horizontal loading, because the whole bent may rotate about the bases of the posts without stressing any of the members.

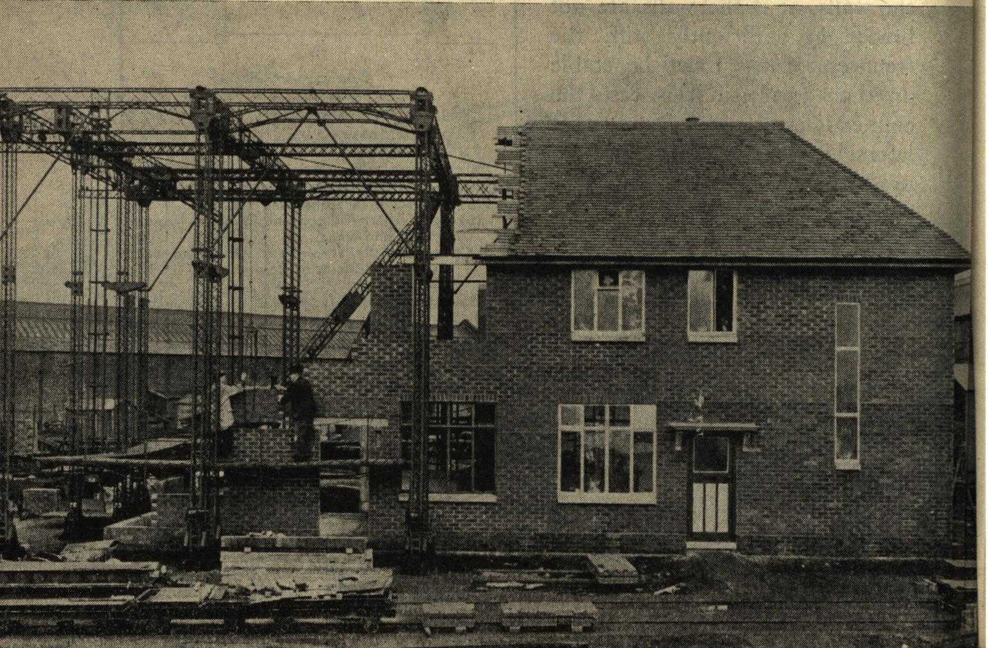
The bent shown in Fig. 86b, although slightly flexible, would be stable enough for the framework during erection ; as soon as the floor or roof were braced and cladded, it would become both stable and quite stiff. An alternative method of achieving stability without placing reliance on the cladding is that shown in Fig. 86c, which does not require stiffness of the end and party walls. This form tends to be too flexible for use in house construction.

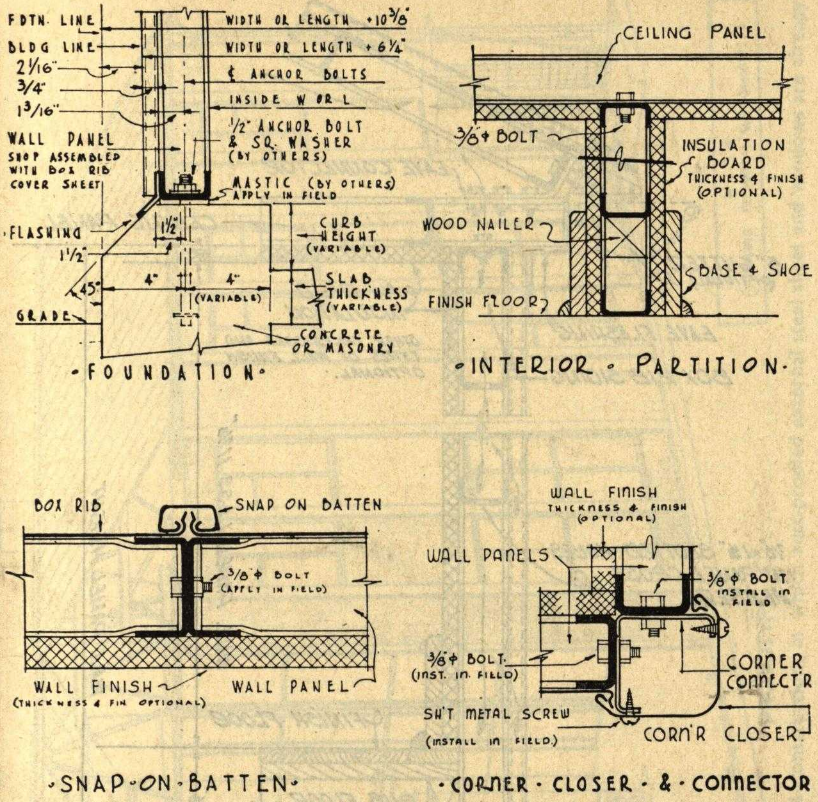
In view of the fact that the bases and caps of the posts do provide appreciable restraint during erection, the method shown in Fig. 86b is very satisfactory, and requires no more than trifling restraint at the first floor connections.

FABRICATION AND ERECTION IN LARGE SECTIONS OR PANELS

Although endless variety is possible in the size of the fabricated units and the method of erection, the tendency at the present time is mostly to select one of the following two alternatives. The first is to use mechanical handling equipment, such as gantries or mobile cranes ; in this event it pays to lift as large a section as can conveniently be delivered to the site. An example of this is the British Steel Constructions (Birmingham) Ltd.'s method as applied to their prefabricated brick wall unit construction, shown by Fig. 87.

87. Prefabricated brickwork construction using temporary steel gantry for erecting wall panels.

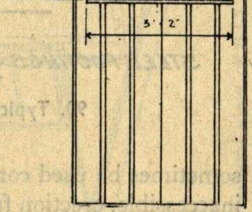




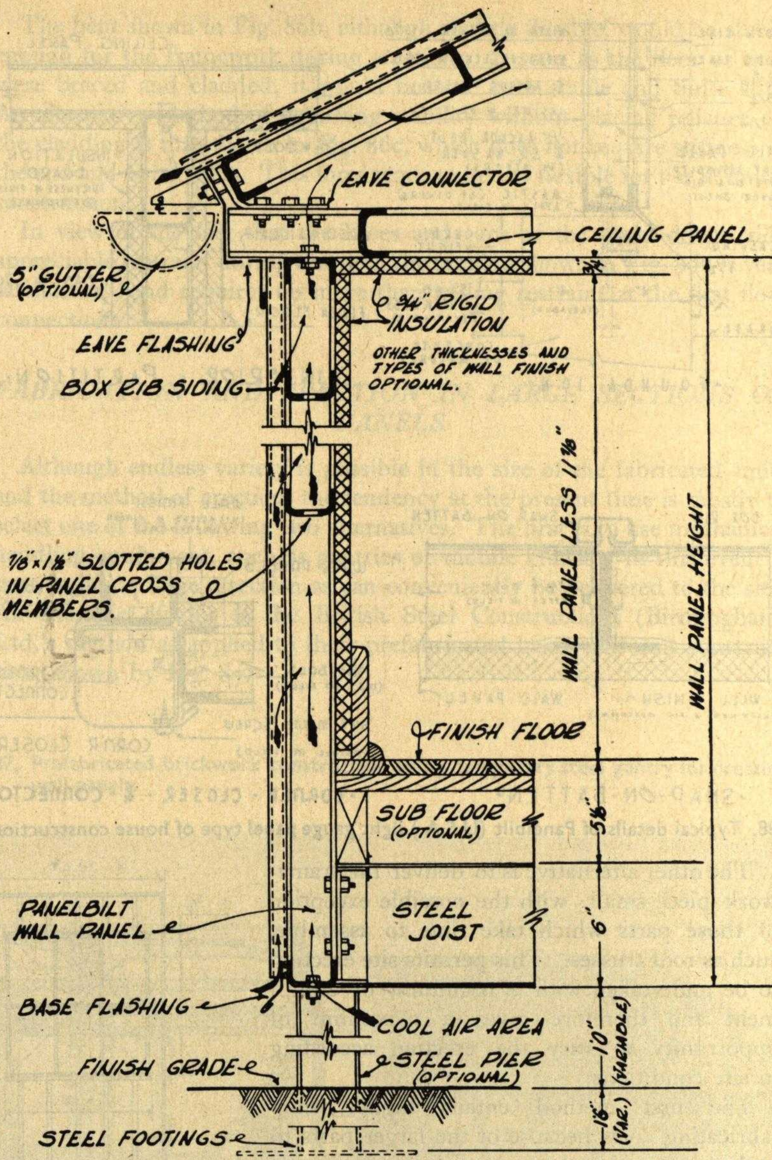
88. Typical details of Panelbilt (U.S.A.) light gauge panel type of house construction

The other alternative is to deliver the framework piece-small, with the possible exception of those parts which take time to assemble, such as roof trusses. This permits site erection to be undertaken with a minimum of equipment and therefore gives a maximum of opportunity to vary the erection according to site conditions.

The first method entails higher shop fabricating costs because of the larger parts to be handled and seeks to recover this by saving of time in erection at the site. However, as the site erection time of the framework of a typical small house is only of the order of 20 man hours, and as cranes or gantries cannot

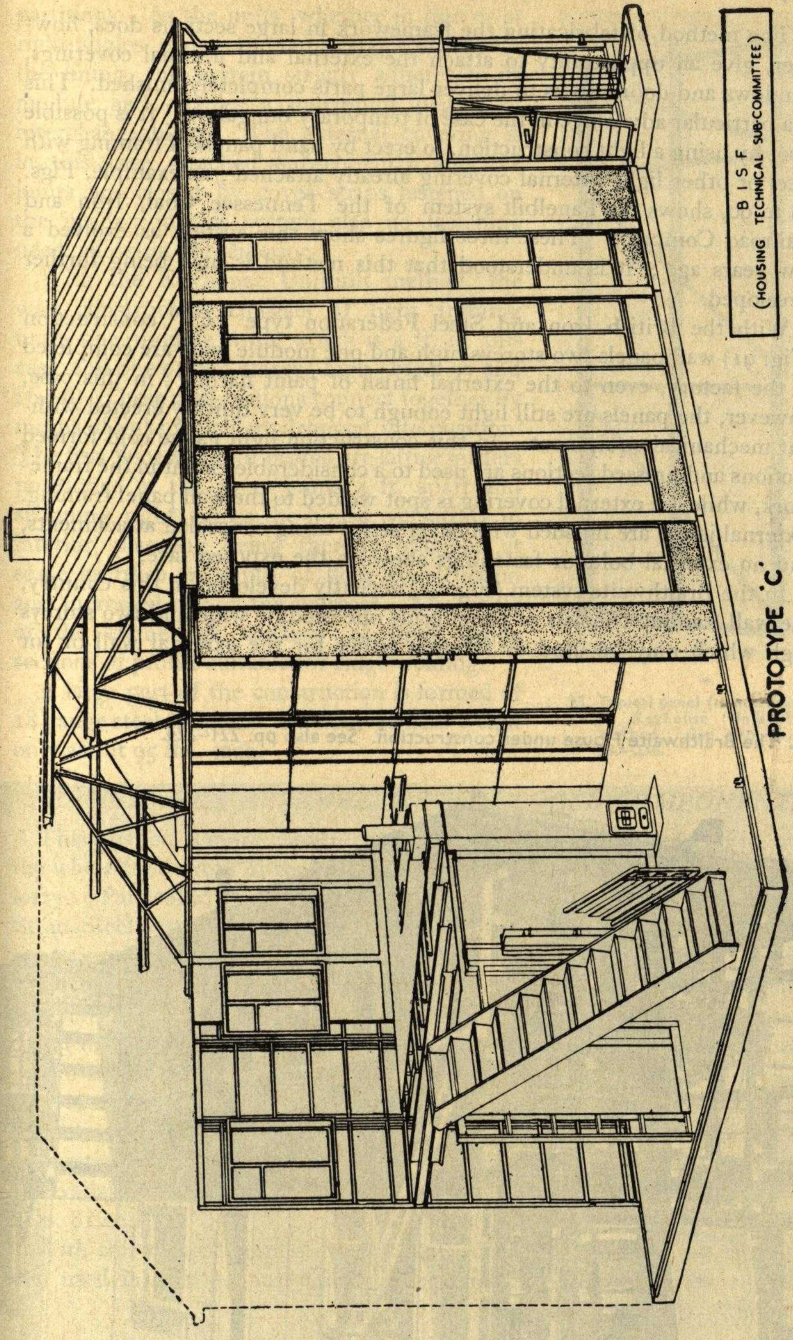


89. Panelbilt wall unit.



90. Typical section through Panelbilt construction.

sometimes be used conveniently on sites which are on sloping ground or inaccessible, erection from small units is the more usual.



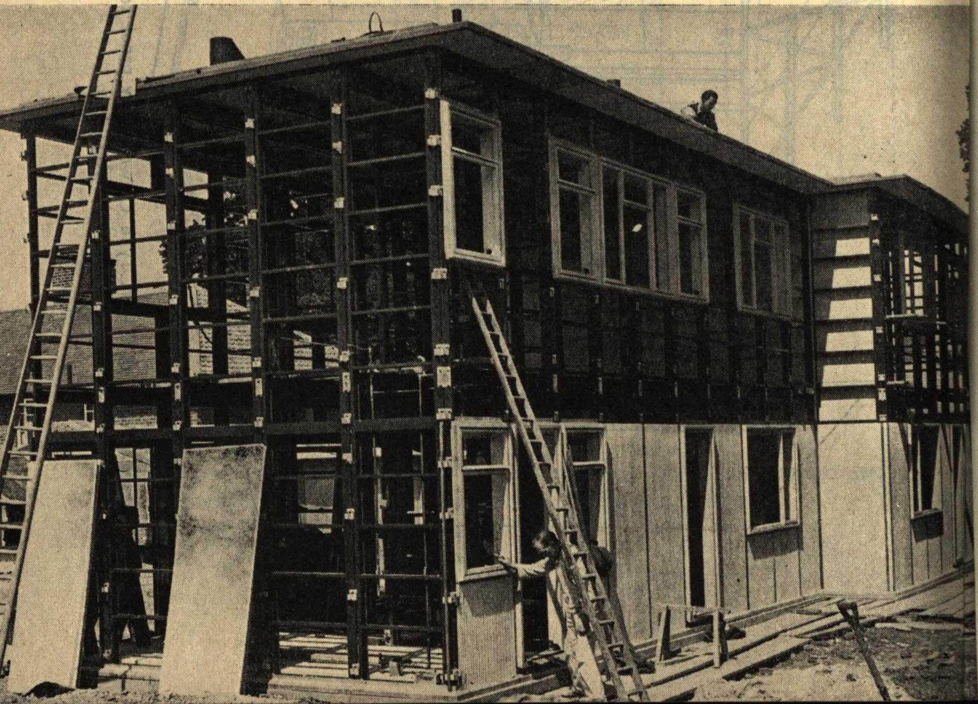
91. General view of B.I.S.F. Type C two-storey panel construction, in which rust-proofed external steel sheet and windows are already attached at the factory before delivery.

The method of fabricating the framework in large sections does, however, give an opportunity to attach the external and internal coverings, windows and doors, so as to deliver large parts completely finished. This is a particular advantage in the case of temporary bungalows. It is possible also, by using a light construction, to erect by hand panels of framing with steel or other light external covering already attached ; an example, Figs. 88 to 90, shows the Panelbilt system of the Tennessee Coal, Iron and Railroad Company. These three figures show this system as evolved a few years ago ; it is understood that this method is now being further developed.

With the British Iron and Steel Federation type " C " construction (Fig. 91) wall panels two storeys high and one module wide are completed at the factory, even to the external finish of paint harling ; in this case, however, the panels are still light enough to be very quickly erected without mechanical equipment. In this construction light gauge cold formed sections and pressed sections are used to a considerable extent in the framework, while the external covering is spot welded to the wall panel framing. External joints are finished with cover strips using concealed attachments, and no external bolts or fastenings show on the exposed face.

In the Braithwaite system (Fig. 92) recently developed in this country, the wall framing consists of panel grids one module wide and two storeys high which may be used as framing either for the external wall or for

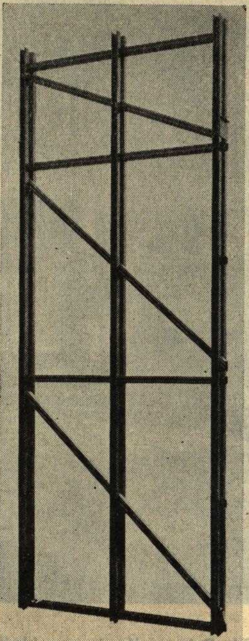
92. The Braithwaite House under construction. See also pp. 221–224.



partitions. As the units, whether in line or at right angles, expose the same length of face for the lining, this system strictly adheres to its module and enables a maximum degree of interchangeability. The external covering is in this case attached subsequently and the joints are closed by cover strips fastened on the inside ; in this system also no fastening need show on the exterior.

With the Keyhouse Unibuilt method, the wall construction consists of light framing units one module wide, which is 4 ft. in this case, and one or two storeys high (Figs. 93 and 164-6). These wall sections connect together by means of links which are dropped into position. The first floor and roof beams are lattice girders positioned at the panel joints 4 ft. apart and spanning right across the house, versatility in interior planning being thereby obtained at some sacrifice in depth of floor construction and increased rise on the staircase. The whole of the framework consists of light gauge sections of profile suitable for ridge welding.

A large part of the construction is formed of 18 gauge steel strip and the floor girders weigh only about 95 lbs. each.



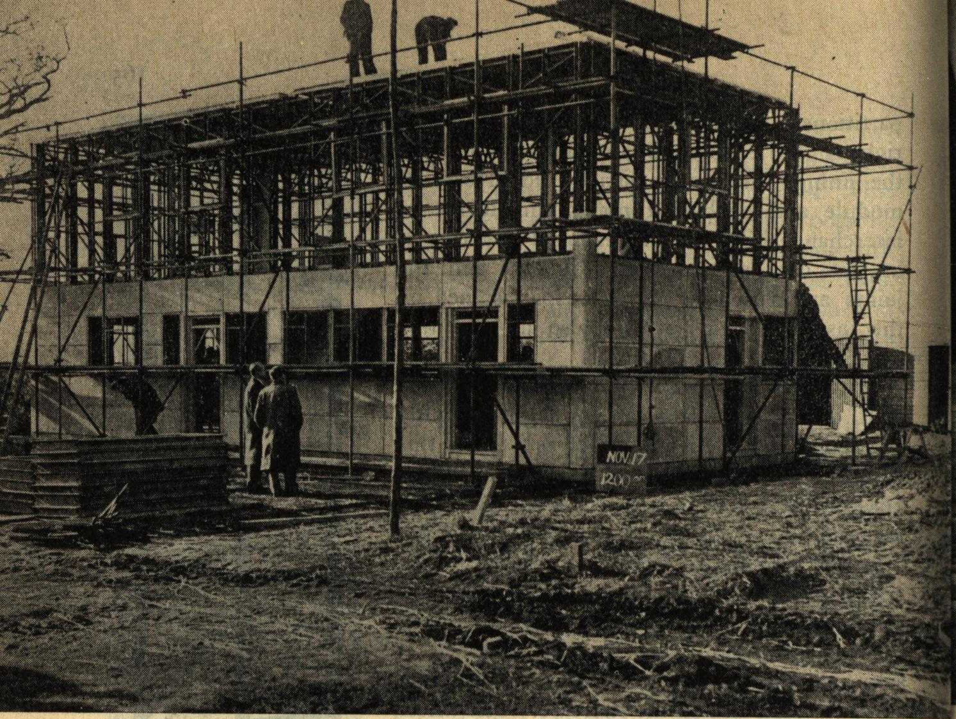
93. Typical panel framework of Keyhouse Unibuilt method. See also pp. 233–236.

FRAMEWORKS ASSEMBLED FROM LOOSE COMPONENTS

This method is more convenient for transport, for example (see Fig. 95) the whole framework of the pair of houses shown in Fig. 98 only needs one lorry. Particularly representative of this type of construction is the Stran-Steel system in America, shown in Figs. 96 and 97, in which light gauge sections are used which are punched for bolting at frequent intervals ; other sections incorporate the slotted members which are a special characteristic of this method, enabling wood or other cladding to be nailed direct to the steel members, the nails being distorted and thereby gripped in the slots.

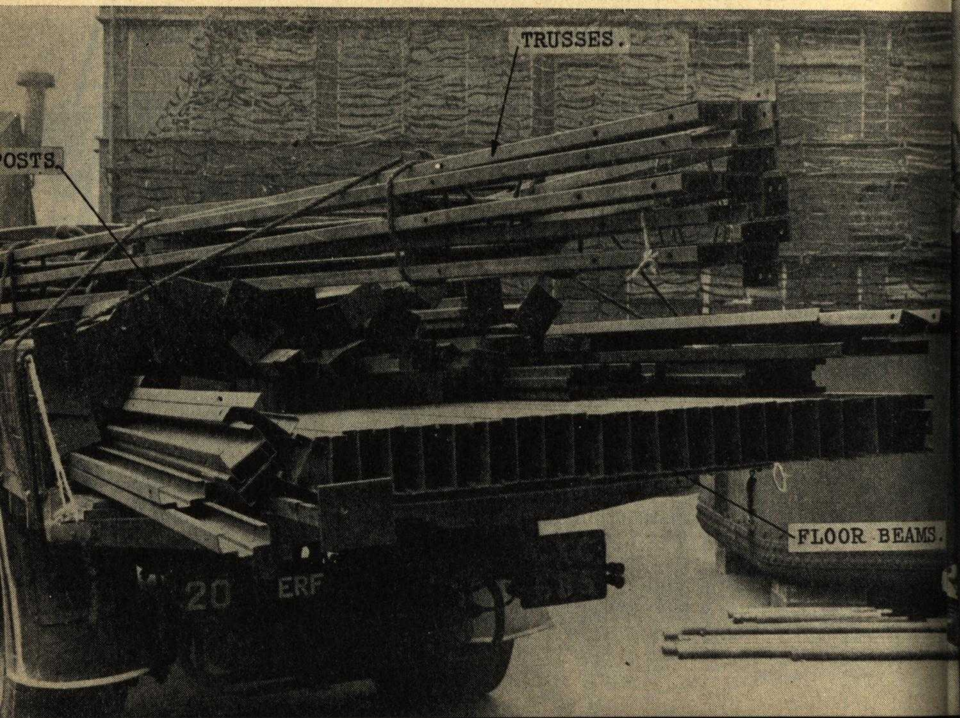
A corresponding type of framework using small hot rolled sections, which weigh more but cost less per ton, is the British Iron and Steel Federation Type " A " House, shown by Figs. 79 and 98. Many methods are available for attaching the coverings ; a few of these have been shown in Figs. 81 and 82.

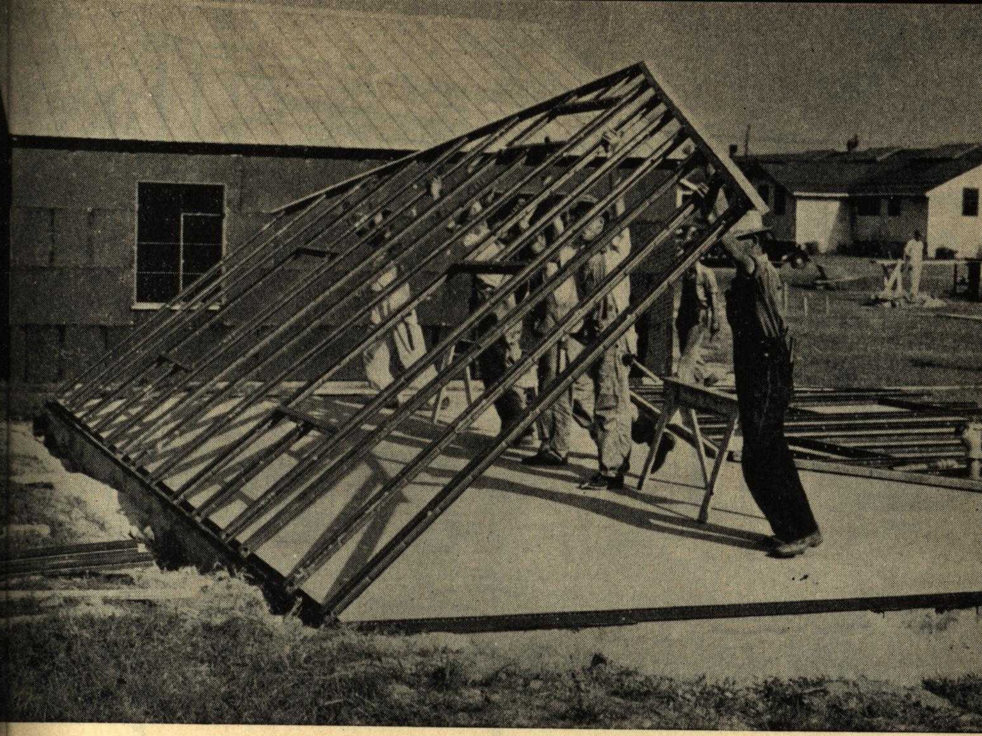
With this type of framework the method of fabrication is the same as that used in steel construction for large buildings and factories, and all



94. Pair of Keyhouse Unibuilt houses under construction. See also pp. 233–236.

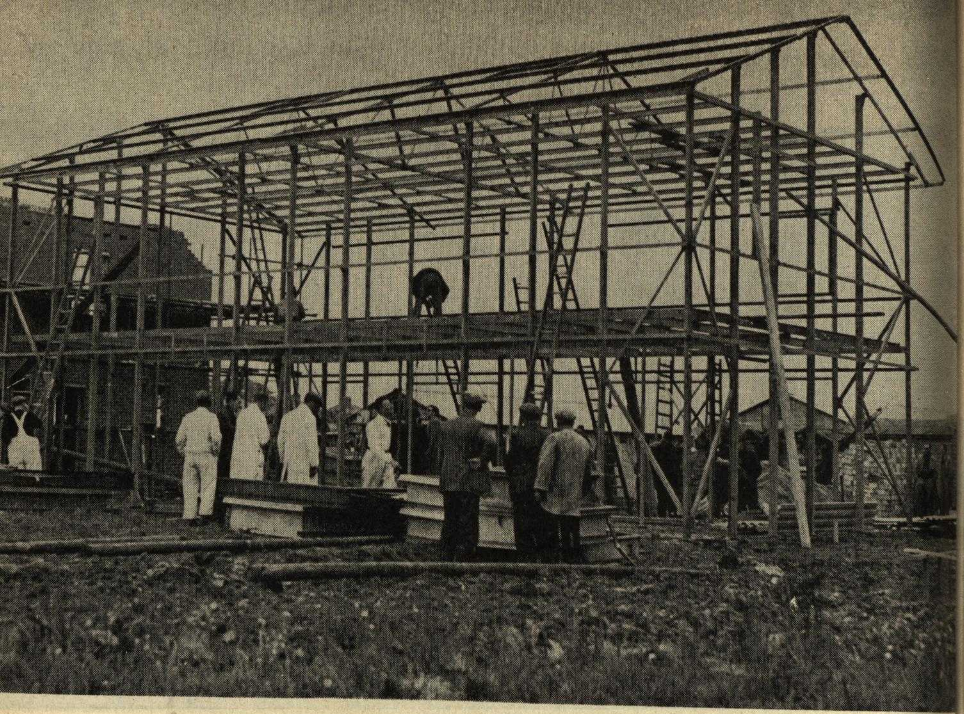
95. Complete frameworks for a pair of B.I.S.F. Type B houses (pp.217–220) make only one lorry load.





96. Stransteel (U.S.A.) gable and framing being erected.

97. Stransteel (U.S.A.) framed house completed.



98. Pair of B.I.S.F. Type A houses one day after commencement of erection.

site connections are effected by bolts. The framework generally is delivered piece-small, but the roof trusses, being fairly light, are delivered whole or in halves for lifting into position at the site in one piece. The floor joists are in one length across the house passing over an intermediate trestle and by the restraint at the end connections help to give stability during erection against horizontal forces referred to in Fig. 83.

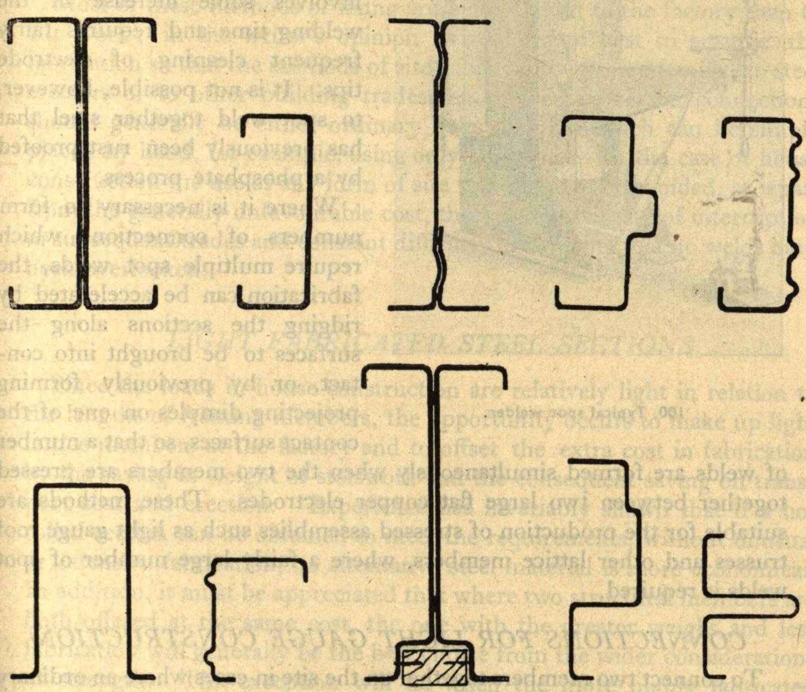
LIGHT GAUGE CONSTRUCTION

Of recent years much interest has been shown in light gauge sections cold formed from mild steel strip. Members of length not exceeding about 10 ft. of channel and similar sections may be formed in this way as pressings; this method is economical, as any holes or notching can be formed in one operation immediately prior to the pressing. Where longer lengths are required the strip is generally cold formed by passing from coils through a cold rolling machine to form sections of the types shown by Fig. 99; within limits of convenient handling any length may be obtained.

In the case of the thicker gauges of strip of widths up to about 8 in., hot rolled strip is available, but for thinner than 16 gauge and for widths beyond that of the hot rolled strip of the same gauge the hot rolled strip is cold rolled to the required gauge. The latter has greater dimensional accuracy, and being bright material it is used in sections for trim, cover strips and other components of prefabricated construction and domestic equipment, where a good finish is required.

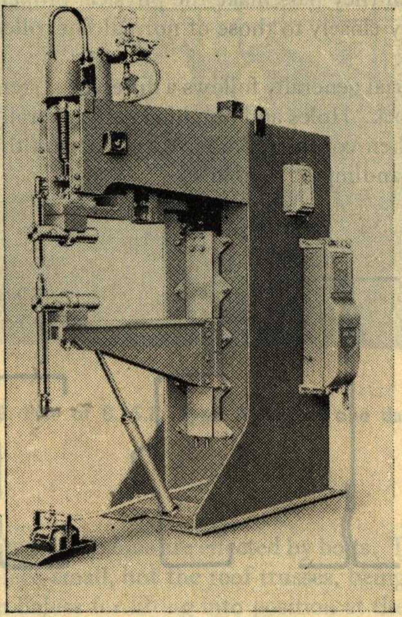
Although both these materials are comparatively low in carbon content, the rolling operations through which they pass make the physical properties of the material correspond fairly closely to those of normal hot rolled structural steel.

Fabrication with light gauge material generally follows a different system from that used for structural steelwork. Holes and notchings are generally punched out by machine so that when considerable repetition occurs the cost is little more than that of the handling of the bars.



99. Typical cold-formed light gauge steel sections, illustrating methods of obtaining compound sections by spot welding and examples of corrugated sections for ridge welding.

Also, with light gauge material, spot welding is one of the most economical methods of attaching cleats and small parts to main members, since it avoids drilling or punching; occasionally, compound sections are formed by spot welding two or more members together, the floor beams shown in Fig. 99 being an example. To obtain the necessary strength a number of spot welds may be used, and are made in quick succession by moving the work about under a machine of the type shown by Fig. 100, though with assemblies a portable spot welder is more often used.



100. Typical spot welder.

To obtain good spot welds clean metal is necessary and the welds cannot be closer than a minimum distance apart if the weld current is to be prevented from by-passing through a previously-made weld. It is possible to spot weld together galvanised steel although this involves some increase in the welding time and requires fairly frequent cleaning of electrode tips. It is not possible, however, to spot weld together steel that has previously been rust-proofed by a phosphate process.

Where it is necessary to form numbers of connections which require multiple spot welds, the fabrication can be accelerated by ridging the sections along the surfaces to be brought into contact, or by previously forming projecting dimples on one of the contact surfaces, so that a number of welds are formed simultaneously when the two members are pressed together between two large flat copper electrodes. These methods are suitable for the production of stressed assemblies such as light gauge roof trusses and other lattice members, where a fairly large number of spot welds is required.

CONNECTIONS FOR LIGHT GAUGE CONSTRUCTION

To connect two members together on the site in cases where an ordinary bolted connection would be prevented by one side being inaccessible, a nut may be previously welded onto one member to receive a set screw. Hank nuts or nuts suitable for projection welding can be used in this case

to avoid the need to arc weld an ordinary nut. Where slight movement of the nut may be necessary to enable a set screw to engage, captive nuts in anchor plates are used.

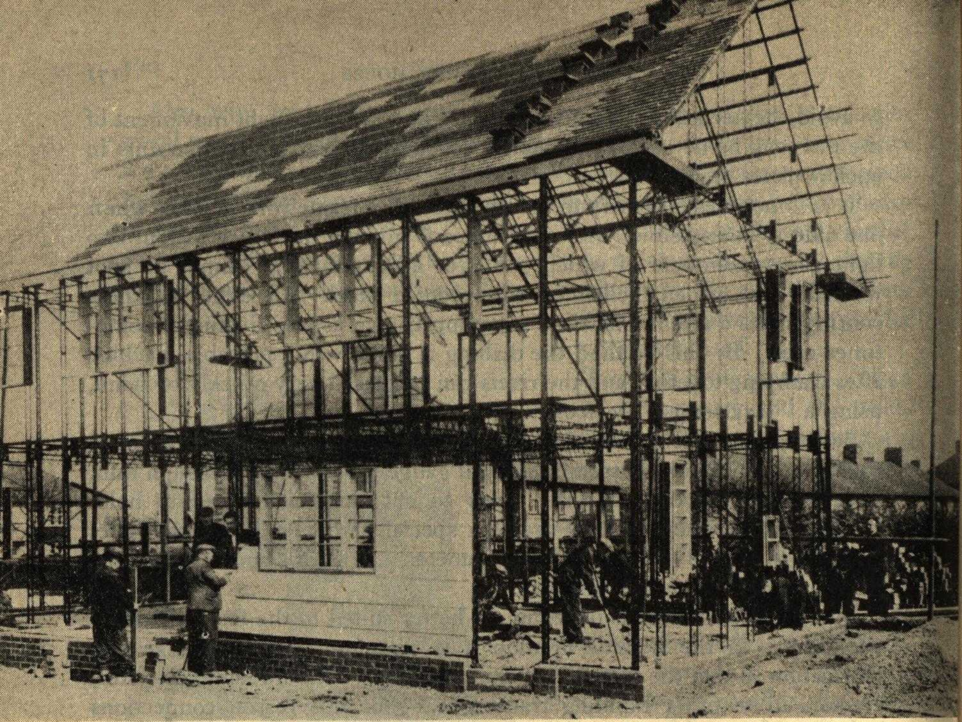
It is sometimes necessary to secure sheets to a framework in cases when one side is inaccessible. At other times it may be necessary to join two light gauge members of which one is of a material that cannot be spot welded, such as enamelled or rust-proofed steel. In either of these contingencies a method of blind fastening known as pop riveting is sometimes used. By this method the drilling is done with a portable machine after clamping together and the rivets can be placed very quickly by hand, using a " lazy-tongs " device.

Self-tapping screws provide another convenient way of securing metal sheets to framing or of assembling light gauge parts which, although thin, have enough thickness for the screw to cut sufficient thread to hold. In this case the screws used are of a special hard metal, and the holes must be drilled of just the correct diameter, i.e. a trifle smaller than the size of the screw over the threads.

Most of these methods of fixing are better suited to the factory than to site work ; in the writer's opinion it is therefore best to arrange the fabrication so that the methods of site connection used are familiar to steel erectors or to other building tradesmen. For this reason connections should generally be either ordinary bolts or clips which can be simply placed by hand, for example, using only a hammer. In the case of house construction the use of any form of site welding is to be avoided, as, apart from the generally unfavourable cost, there is a possibility of interruption to subsequent trades and constant difficulty in ensuring that no welds have been overlooked.

LIGHT FABRICATED STEEL SECTIONS

Since the loads in house construction are relatively light in relation to the lengths of framing members, the opportunity occurs to make up light lattice members at the factory and to offset the extra cost in fabrication by the saving in weight of steelwork and the consequent saving on transport cost and erection. Experience has invariably shown that if a hot rolled section can be obtained to meet the requirements, without unusual or extensive fabrication, no alternative steel material is more economical. In addition, it must be appreciated that where two structural members are both offered at the same cost, the one with the greater weight and less fabrication will generally be the best choice from the wider considerations of strength. The exception will be when the more highly fabricated members are so arranged as to avoid tendencies for sway or lateral deflection and when the fabrication makes possible very economical attachment of the cladding.



101. Framework of pair of houses using method of Hill's Patent Glazing Company. See also Fig. 60.

In America for some time light steel beams, both of deep thin web sections and in the form of open web joists, have been produced, the web latticing being generally fillet welded to the top and bottom bars. In this country, a system with light lattice framing members is that used by Messrs. Hills Patent Glazing Co., shown in Fig. 101; the fabrication in this case may be done by arc welding or by resistance welding.

SITE ERECTION

With frameworks which are delivered loose, the largest and heaviest piece to fix is the roof truss, which is generally delivered in halves or in one piece. For this type of erection, a " stick " is often the only tackle required. During erection the stability of the framework can best be obtained by commencing from one end or from both corners of one end; if wind bracing is provided in the external wall cavity at the corners, as it is in the British Iron and Steel Federation types, little guying is required. If stability of the external wall against wind pressure is obtained from the floor and roof, it may be necessary to ensure that all members are securely bolted up as erection proceeds.

TIME OF ERECTION

The time required to erect the framework of a pair of houses depends more on the number and the type of the connections than on the weight of the framework.

Eight hours for five or six men may be taken as the average for a pair of houses ; it can be reduced by the use of connections which are easy to make and by the provision of templates for the quick positioning of stanchion bases, but if much cost is spent in this direction it will not be recovered by time saved and will require other advantages if it is to be justified.

PREVENTION OF CORROSION, AND PAINTING

Since steel is practically everlasting in protected positions such as are provided in well-constructed framed domestic houses, and since it experiences no permanent volume changes with course of time, the life of a steel-framed house is in fact determined by the properties of the external facing, and by the measures taken in the design to prevent condensation. The life of a framework will normally greatly exceed the life of the protective painting on those parts of the framework which are inaccessible for maintenance ; it is therefore worth while to pay careful attention to the painting of the steel.

One of the best preservatives for clean structural steel is genuine red lead paint, applied in two coats ; if this steel is not in a position exposed to condensation no additional treatment will be necessary.

Where steel components are exposed externally, in addition to touching up any damage to the shop paint at least one coat of a good quality tough impermeable paint resistant to the action of light should be applied after erection.

For roof sheeting, steel sheets protected with bitumen composition are justified because of the difficulty of maintenance, but where steel wall sheeting is used there is more variety of choice.

As mentioned earlier, very satisfactory results have been obtained by the use of paint harling for the exterior of steel houses. The method (which is patented) consists of applying a thick covering of a mixture of white lead, stand oil and gold size and of throwing on to this graded granite chippings to obtain the rough-cast finish. These chips are themselves coated with the paint mixture before being applied. This type of finish, when applied to an ordinary steel surface, has been found to be still in good condition after 10 years.

The fact that red lead is a rust inhibitor makes it an ideal material for priming steel for external work, and as an alternative to paint harling a durable finish for external steel can be obtained by means of a red lead primer and two coats of a good finishing paint.

In that case the useful life will depend upon the impermeability to moisture of the finishing coats and on the cleanness of the steel before applying the red lead primer.

For rust-proofed and galvanised steel the advantages of a red lead paint are not so great, since the life of external light gauge steel is frequently determined by corrosion starting at holes made for fixing sheeting bolts. Such holes should preferably be made in the factory before galvanising. Owing to the difficulty of registering holes in light gauge material, a satisfactory and more usual alternative is to provide a lead washer through which the exposed end of the bolt bears on the sheet; if this method is adopted the bolt should also be bedded in red lead putty or in a suitable mastic before tightening.

Because steel rust-proofed by the phosphate process has an absorptive surface it is usually primed in the factory before delivery, to prevent the advantages of the treatment being lost through absorption of damp or oil on the surface. Steel treated in this way, even if deeply scratched, will not commence to rust and lift off the paint. For touching up scratched and damaged paint at the site before applying finishing coats, ferro-chrome can be used, more particularly on steel which has a red oxide primer. For steel components which are primed or completely painted before leaving the factory, an iron oxide paint is generally used as a primer, partly owing to the regulations restricting the use of red lead paint in factories and partly because red oxide is suitable for dipping and stoving.

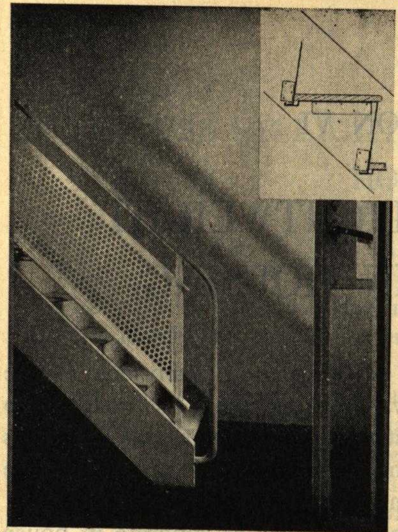
STEEL BUILDING COMPONENTS AND METAL TRIM

Components of a house which are suitable for manufacture in steel include window surrounds, door frames, porches, staircases, skirtings and other metal mouldings. With most of them the possibilities of mass production are not yet known, but in the future they may become more than mere substitutes for timber. At present some have advantages over wood in respect of cost or time to fix. Others, such as mouldings, and in particular skirtings, cost more than wood, but do not split or shrink. If sherardised or rust-proofed and finished with stoved enamel, they give a much better finish than wood.

The use of steel skirtings and a concrete ground-floor slab, without cavities, is a good and inexpensive investment, as it keeps away rats and mice.

Metal mouldings are generally cold formed (cold rolled) sections, but most other internal components are pressed.

Staircases of the type shown by Fig. 102 are delivered in two parts, the stairs and the balustrading. The former is designed for jig assembly of pressings by spot welding and is quieter in use than a wood staircase. A great variety of types of balustrade is possible.

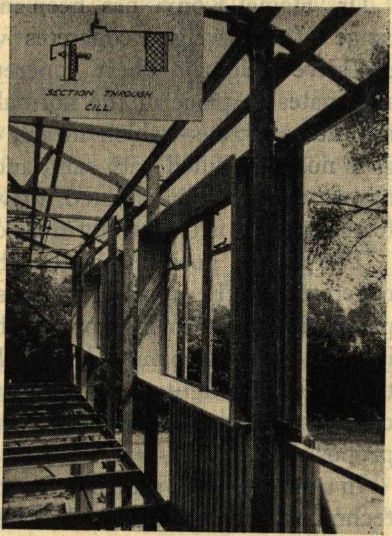


102. Typical domestic light steel staircase.

Window surrounds may either be made to form a reveal and window board to the interior only or may form external and internal linings to the reveals, and a cill, either all in one piece (as Fig. 103) or in two parts, internal and external, connected in the plane of the metal window.

Both window surrounds and door frames may be resistance mitre welded at the intersections, these welds being done at rates up to 200 per hour. Window surrounds may be galvanised for painting at the site or rust-proofed and primed. All metal parts for the interior can, however, with advantage be completely painted at the factory with a stoved enamel finish ; the finish provided, besides covering all surfaces instead of merely those visible when decorating, is much superior in appearance to hand painting.

103. Typical hot galvanised light gauge steel window sub-frames.



SECTION VI

THE USE OF LIGHTWEIGHT CONCRETE IN HOUSING

WHILE many experts have been devoting their attentions to the techniques to be applied in post-war housing, there has resulted no uniformity of solution. In contrast to the last Paper, this section is devoted to a consideration of the means by which we can extract the greatest utility from the load bearing form of construction.

Probably the principal objection to the use of concrete in house building lies in the excessive weight of the material and in the fact that its potential strength is far greater than it is ever called upon to supply.

Dr. Hajnal-Kônyi has been investigating the possibilities in the range of lightweight concretes which avoid the disadvantage of excessive weight. These concretes either use special lightweight aggregates in place of the normal gravel, or are what is known as no-fines concrete—which means concrete having air spaces in the gaps normally filled with sand and fine aggregate. As a third alternative, they may be aerated, in which case some gas-producing or foaming agent is used to form air cells throughout the concrete.

The author goes on to describe the ways in which lightweight concrete may be applied to house construction, showing how the possibility of employing powered handling plant on the site has made it practicable to use much larger blocks and slabs than was previously the case. The lightness of the new range of concrete products is of course by no means the least of the reasons why this is an economic proposition.

In some ways the methods described in this Paper appear to be less technologically advanced than those previously discussed. This impression should not be too readily accepted, for the author has moved on to a study of this subject from an expert knowledge of reinforced concrete shell construction which of all the new forms is one of the most graceful and slender.

THE USE OF LIGHTWEIGHT CONCRETE IN HOUSING

By Dr. K. HAJNAL-KÔNYI, M.I.Struct.E.

" THE resources of the building industry will at the end of the European war be insufficient both in materials and labour to meet the country's immediate needs. It is necessary that we should be prepared to a greater degree than after the last war to supplement those resources by the use of alternative methods and materials which would enable all available materials and all the different types of labour in the industry to be used to the maximum possible extent."(1)* This statement in *Housing Manual*, 1944, issued by the Ministry of Health and the Ministry of Works, provides the justification for the following article, which describes the properties and potentialities of a group of materials that will be called on to play a leading role in speeding up the provision of houses. Lightweight concrete is already firmly established as a building material on the Continent and in the U.S.A. and is likely to become equally popular in this country.

I. GENERAL CONSIDERATIONS

Among the alternative materials which may be used in walls of houses instead of traditional materials such as brick or stone, lightweight concrete is the most important. There is no strict definition for the term " lightweight concrete." In its most general interpretation, it indicates concrete of a density not exceeding 120 lb./cu. ft. (as against 140 to 150 lb./cu. ft. in the case of ordinary concrete), but the density of lightweight concrete suitable for application in housing is between 65 and 100 lb./cu. ft. and the most favourable range is between 70 and 90 lb./cu. ft.

Before we proceed with the description of the materials known as lightweight concrete and of the various methods of their use, let us consider the requirements which have to be fulfilled by the walls of a house.

In a building with load bearing walls, which is the usual type of construction for dwelling houses of not more than two storeys, one may be inclined to think that the compressive strength of the material is of primary importance. Brick has a high crushing strength, and although the crushing strength of a 9-in. brick wall of about 9 ft. height is only a comparatively small fraction (about one-third) of the strength of a single

*Numbers in brackets in the text refer to books and other sources of information listed in the bibliography at the end of this Section.

brick, it is far in excess of what is actually necessary for carrying the vertical loads in such a building. Whilst the brickwork at the ground floor level of a two-storey house will not usually be subjected to a greater pressure than 1¼ tons/sq. ft. (about 20 lb./sq. in.), it would be a very poor brick which had a crushing strength of less than 60 tons/sq. ft. (about 950 lb./sq. in.) (2). Failure of brick walls is usually due to their weakness in shear and tension, which occur by unequal settlements or horizontal forces (blast, earthquake), and not by compression. Thus, from the point of view of load bearing, materials substantially weaker in compression than brickwork may be used without disadvantage.

The transmission of loads to the foundations is only one of the functions of the wall. Other important functions and requirements are :

Thermal insulation.
Sound insulation.
Prevention of moisture penetration.
Prevention of condensation.
Fire resistance.
Maintenance and durability.

These requirements are discussed in detail in the Report of the Burt Committee on House Construction (3). The Report has established certain "standards of habitability" which are desirable in a dwelling house. As far as the thermal insulation of the walls is concerned, the desirable standard is 0·15 to 0·20 B.Th.U./sq. ft./hr./°F. as against 0·30 of an 11-in. cavity exterior wall plastered internally (cavity unventilated) and 0·28 of a 9-in. brick external wall, roughcast externally*). The desirable standard of insulation against air-borne sound is 55 db. as against 50 db. of a 9-in. brick party wall plastered both sides.

It may be seen from these comparisons that the traditional brick wall falls short of the desirable standards, as regards both heat and sound insulation.

Many attempts have been made to use ordinary concrete, either cast in situ or in precast units, instead of brickwork, often with some reinforcement, both in single leaf and in cavity walls. Since the thermal insulation of ordinary concrete is even less than that of brickwork, such walls must be provided with an internal lining to achieve the desirable standard and to prevent condensation. The main advantage of ordinary concrete, its great compressive strength, cannot be utilized in walls of houses. On the other hand, lightweight concrete has all the properties desirable in house construction. Its density can be adjusted, so as to give both satisfactory thermal insulation and sufficient strength to carry the comparatively small loads occurring in this type of structure. At the same time, it is nailable and easy to cut.

*A high value of this coefficient means low insulation.

II. TYPES OF LIGHTWEIGHT CONCRETE AND THEIR CHARACTERISTICS

Lightweight concrete can be made of a great variety of materials in different ways. We distinguish three main groups :

(a) Lightweight concrete made of lightweight aggregates.
(b) No-fines concrete.
(c) Aerated or cellular concrete.

The first group allows the greatest variety of applications, both in precast and in in situ work; the second is confined to concrete cast in situ. In the following paragraphs some characteristics of the three groups are given.

(a) LIGHTWEIGHT CONCRETE MADE OF LIGHTWEIGHT AGGREGATES (4) (5)

Lightweight aggregates may be divided into three main groups :

(i) Materials used in the state in which they occur naturally and which require no treatment beyond a preliminary crushing and washing to separate undesirable constituents.
(ii) Materials arising as by-products from other processes.
(iii) Artificial and processed aggregates, specially manufactured as lightweight products.

(i) *Natural lightweight aggregates.*

The only natural lightweight aggregate in common use is pumice, a material of volcanic origin, occurring in many countries but not in Great Britain. It has usually been imported from Germany, where there are large deposits on the Rhine in the neighbourhood of Neuwied, near Coblenz. It has been used in large quantities in housing in Germany, but it is not likely to be of importance in this country.

(ii) *By-product lightweight aggregates.*

These are sawdust, furnace clinker and coke breeze.* The major disadvantage of sawdust-cement is a very high shrinkage on drying and expansion on re-wetting (6). For this reason, it is not a material to be recommended in housing.

Furnace clinker is a residual product of the combustion of coal (7). It has been used in most of the systems described in the Burt report, in many of them with satisfactory results. However, " certain clinker aggregates have been found to cause serious expansion of any concrete in which they are used. This has been shown to be due to the presence of certain types of unburnt, or partially burnt, coal; only certain coals cause trouble in this way " (4). Simple tests for the detection of clinker aggregates which are unsound are described in British Standards Specification

*Shredded wood is used in the manufacture of wood wool building slabs, marketed under various trade names. Since the nature of the main component of this material is very different from that of aggregates usual in concrete or lightweight concrete, the writer does not consider that wood wool falls within the scope of this article.

No. 1165 (8). " One of the major difficulties in the use of clinker as an aggregate is the very wide variability of its quality. The best clinkers yield satisfactory concretes which are not particularly light in weight. Clinkers containing high contents of combustible matter yield lighter concrete, but the other physical properties are much inferior. Unsound clinkers are definitely dangerous and have led to serious building failures " (4).

" Coke breeze consists of small coke derived from gas works or coke ovens. In general, the properties of coke breeze concrete tend to be somewhat unsatisfactory." (4).

(iii) *Processed lightweight aggregates.*

These are foamed slag, expanded clays and shales, expanded slate and expanded vermiculite. At present only the first material is of practical interest in this country.* Expanded slate is an excellent material, but the places where it could be produced are far from the districts where it would be used. Natural deposits of the mineral vermiculite are not available in this country. Expanded clay has been extensively used, with satisfactory results, in U.S.A., under various trade names. Production in this country is in the experimental stage.

Foamed slag is a lightweight, cellular material, made by treating molten blast-furnace slag, obtained in the manufacture of pig iron, with a controlled quantity of water (9). The product, after cooling, is crushed and graded for aggregate, usually into two gradings, coarse (½-in.—⅛-in.) and fine (⅛-in. to dust). Fine foamed slag shows cementitious properties which contribute to the development of strength of mortars made from it.

Foamed slag concrete has been extensively used in U.S.A. and Germany for many years, especially in the neighbourhood of the iron-producing centres. The average weight of the coarse aggregate is about 30 to 32 lb./cu. ft.; in order to comply with B.S.877 it should not exceed 37 lb./cu. ft. The average weight of the fine aggregate is about 40 to 42 lb./cu. ft.

As stated in (1), " at the present moment, the variety of concrete which appears from every point of view to compare most favourably with brickwork as a walling material is foamed slag." For this reason, the following data refer to foamed slag concrete, but it should be noted that concrete made with expanded clays or shales has similar properties. Concrete made of expanded slate and expanded vermiculite is lighter than foamed slag concrete if the strength is equal.

Strength and density.

The range of strength and density which can be obtained with foamed slag concrete is illustrated by the test data in the following table (10), taken from the *Journal of the Royal Institute of British Architects*, December, 1944.

*At the moment there are two plants in Great Britain ; one in England (Scunthorpe), one in Scotland (Glasgow). If foamed slag is to be used in post-war housing in substantial quantities, more manufacturing centres will be required. Foaming plants can be established at blast furnaces.

LABORATORY DATA ON FOAMED SLAG CONCRETE

Cement (normal Portland)	Mix. Proportions (Vol.) Fine foamed slag	Coarse foamed slag	Water/cement ratio (wt.)	Compressive[1] Strength (lb./sq. in.) 28 days	3 months	Weight per cu. ft. at 3 months (lbs.)	Dimensional Changes (Linear %) drying shrinkage	moisture expansion	Thermal Conductivity BThUs/sq. ft./hr./in./1°F. (specimens matured at 64°F and 65% relative humidity)
1	1	2	0.45	4495	5213	114	0.056	0.044	
1	1½	4½	0.67	1130	1220	85½	—	—	
1	2	4	0.74	1540	1722	89	0.049	0.043	2.2 (at 81 lb./cu. ft.)
1	3	3	—	—	—	83	0.053	0.048	
1	2	6	0.87	710	770	75	0.023 when steam cured	0.031	2.2 (at 85 lb./cu. ft.)
1	3	6	1.05	644	680	81	0.044	0.041	
1	2½	7½	1.13	600	710	79	0.042	0.034	1.02[2] (at 41 lb./cu. ft. and 4.1% free water content) 1.7 (at 68 lb./cu. ft. and 4.7% free water content) 1.9 (at 71 lb./cu. ft. and 5.3% free water content)
1	4	8	1.39	469	560	76	0.044	0.037	
1	3	9	1.29	540	600	71	0.043	0.033	
1	4	12	1.75	380	420	67	—	—	
1	6	12	2.11	257	306	70	—	—	

(1) After maturing under damp sacks for 7 days, then in air at 64°F. and 65% relative humidity.
(2) Made from a specially selected very light aggregate with little tamping in filling moulds.

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This table shows the effect of the variation of the mix on the compressive strength and density of the concrete. Both are substantially increased if foamed slag sand is replaced by river sand as may be seen from the following table.(4)

Mix proportions (vol.) Cement (normal Portland)	River Sand	Coarse foamed slag	Water/cement ratio (weight)	Compressive strength at 28 days lb./sq. in.	Weight per cub. ft.
1	1	2	0·45	6400	126·5
1	2	4	0·74	3080	115·0
1	4	8	1·39	770	106·5

Of course, the foamed slag sand may only partly be replaced by river sand and many combinations are possible to produce lightweight concrete varying in strength and density. There is a direct relation between these two characteristics. For a given mix the maximum strength is obtained with a water content of about 20 per cent of the weight of the dry mix. It is essential that the foamed slag should be saturated with water before cement is added. Many failures have been due to the non-observation of this rule.

Apart from the dense mix 1 : 1 : 2, which is of no interest in housing, the drying shrinkage is hardly influenced by the mix. It is advisable to add cement by weight.

An important characteristic of foamed slag concrete is the comparatively favourable ratio of compressive strength : modulus of rupture.

Thermal insulation.

The favourable behaviour of concrete made with lightweight aggregates with regard to thermal insulation is due to the presence of air-filled cavities. The insulation afforded by such concretes is very much reduced if they become wet. The thermal conductivity of loose foamed slag is 0·87 B.Th.U./sq. ft./hr.1°F./1-in. thickness, that of foamed slag concrete of 1 : 2½ : 7½ mix may vary from 1·5 to 2·2. The normal value is between 1·7 and 1·9. This compares with 2·3 to 2·8 in clinker concrete, 5·5 in Fletton brick and 6·7 to 7·0 in ordinary concrete (see footnote on p. 178).

Sound insulation.

The sound insulation of a homogeneous wall increases with the mass per unit area in a logarithmic relation. The desirable standard for party walls cannot be obtained by a single leaf light-weight concrete wall of reasonable thickness, but only by a two-leaf construction. (See p. 193).

Fire resistance.

With the exception of clinker concrete, concrete made of lightweight aggregates behaves more favourably in fire than ordinary concrete. The fire resistance of lightweight concrete is far in excess of the requirements in a dwelling house and need not be discussed in detail.

Water-proofness.

Water in liquid or vapour state will permeate most types of brick and stone and all the usual types of mortar. In walls composed of these materials

there are three possible ways in which moisture can enter—through the units, through the mortar joints or through cracks between the units and the joints. Water is drawn through such materials and cracks by capillary attraction. This capillary force may be supplemented by wind pressure on the face of the wall. Any hair cracks in the wall surface are likely to lead to serious penetration. For all these reasons a solid wall of small units embedded in mortar cannot be relied upon to exclude damp, and a 9-in. solid brick wall is not satisfactory for small house construction. The trend in recent years has been towards the 11-in. cavity wall (3).

Quite different is the behaviour of lightweight concrete. If lightweight concrete is exposed in a vertical position, driving rain or a spray of water will penetrate according to the strength of the driving force. When it has penetrated one or two in. deep, it will lose its force and will be partly absorbed in the outer skin and will partly flow down by its own gravity through the cavities of the outer layers.

The realization of this property of lightweight concrete is essential for its proper application in walls.

(b) NO-FINES CONCRETE (3)

No-fines concrete is a concrete composed of cement and coarse aggregate only, the fine aggregate of a normal concrete being omitted, so as to leave many uniformly distributed voids throughout its mass. It may be used for load-bearing external and party walls, partitions and chimney breasts. A number of houses have been built in England and Scotland with cast in situ walls of this type of concrete.

Strength and density.

The following table gives existing data on the strength of the nearest mixes to those recommended.

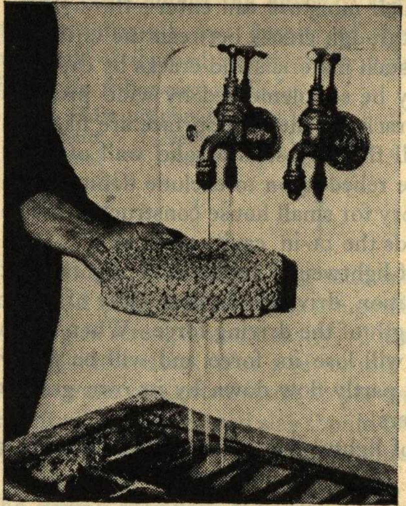
Aggregate	Mix (vol.)	Water/ cement ratio	Compressive strength lb./sq. in. in three months
Gravel (¾-in. to ⅜ in.)	1 : 10	·45	860
Light clinker aggregate	1 : 6	·60	410

The ratio compressive strength : tensile strength of no-fines concrete is less favourable than that of ordinary concrete. Its shear strength is also low. Consequently slender piers and eccentric loading are to be avoided.

The weight of no-fines concrete is some two-thirds that of a normal concrete with a similar material as aggregate.

Thermal insulation.

The thermal insulation of a no-fines concrete wall with ordinary aggregate is similar to that of a solid brick wall of the same thickness. The usual 8-in. thick wall with heavy aggregate should have additional insulation to make it comparable with an 11-in. brick wall. An 8-in. wall with clinker



104. Effect of running water on porous concrete.

aggregate, rendered externally and plastered internally, reaches the insulation standard of an 11-in. brick wall.

Sound insulation.

The sound insulation of no-fines concrete is equivalent to that of a brick wall of approximately equal mass per unit area. A higher value than that of a 9-in. brick party wall, which is desirable, may be obtained by using a discontinuous construction.

Fire resistance.

With clinker aggregate care is to be taken to exclude combustible matter.

Water-proofness.

A no-fines concrete wall of 8-in. thickness with a suitable rendering and good detailing is comparable to a well constructed 11-in. cavity brick wall with regard to resistance to moisture penetration.

Its behaviour is similar to that described in connection with concrete made of lightweight aggregates. (Fig. 104). The water penetration is limited to about twice the diameter of the coarse aggregate.

(c) AERATED OR CELLULAR CONCRETE

This type of concrete is made of ordinary clean sharp sand and cement by the addition of some material producing cells. According to the properties of the additional material, we may distinguish two groups.

(a) Materials producing gas during or after mixing.

(b) Foaming agents, completely soluble in water.

The first group is mainly represented by metals in pulverised form (zinc, aluminium, aluminium-magnesium alloy), the second by synthetic resin, gelatine, etc., often added to the mix in liquid form. There are a number of proprietary brands, belonging to either of the two groups. If a foaming agent is used, aeration is obtained by stirring rapidly in a whisking machine whereby air is induced into the mass in the form of minute stable bubbles.

The strength and thermal conductivity of cellular concrete are comparable with those of foamed slag concrete of equal density. E.g., cellular concrete made with " Cheecol " and ordinary Portland cement : sand

mortar of 1 : 3 of a density of 85 lb./cu. ft. has a crushing strength of 1,100 lb./sq. in. at 28 days, and a thermal conductivity of 2·9. The density depends on the water : cement ratio and may vary between 45 and 100 lb./cu. ft. The thermal conductivity of a material of 50 lb./cu. ft. is approximately 1·2.

III. METHODS OF APPLICATION IN WALLS

Lightweight concrete may be used in the walls of houses as both non-load-bearing and load-bearing material. As non-load-bearing material it is in common use in partitions. It has often been adopted as permanent shuttering to cast in situ walls and as the inner leaf of cavity walls in framed buildings. In all these cases lightweight concrete is used in the form of precast slabs or blocks, the size and shape of which vary to a great extent.

In load-bearing walls three methods of application may be distinguished.

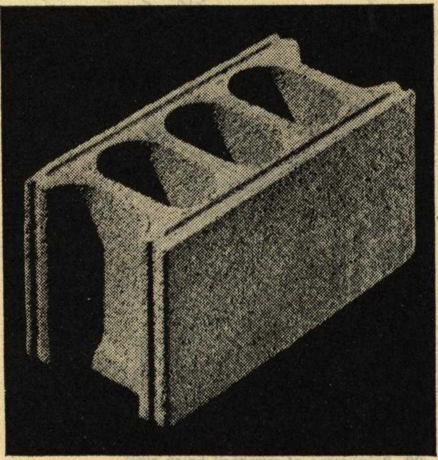
(a) Precast blocks and slabs of substantially larger size than bricks, without reinforcement, erected by the same technique, i.e. embedded in mortar.

(b) Large reinforced pre-cast units, assembled by cranes.

(c) Cast in situ.

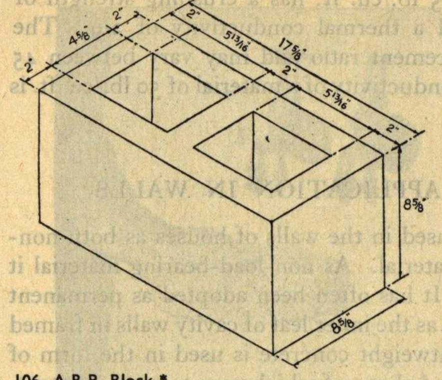
(a) PRECAST BLOCKS AND SLABS WITHOUT REINFORCEMENT (12)

Both in U.S.A. and Germany precast masonry units of light weight concrete are very popular. In Germany a number of various types of hollow blocks are on the market, in U.S.A. only one standard overall size ($15\frac{3}{4}$-in. $\times$ $7\frac{3}{4}$ in. $\times$ 8 in.) is manufactured. It has either three oval or two square cavities (Fig. 105). More than a tenth of the houses in U.S.A. are built in each year from precast concrete units. This has been done through the development of this simple block rather than any of the more complicated systems which more nearly represent the usual idea of prefabrication.

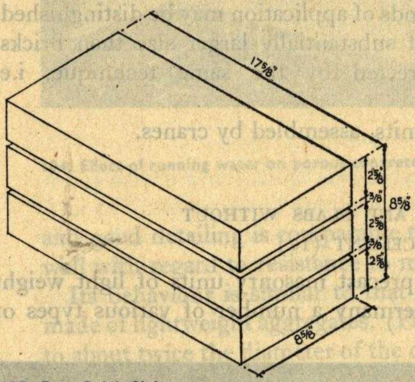


105. Standard U.S.A. masonry unit.

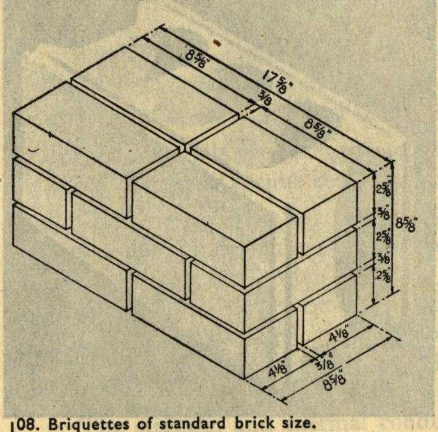
In this country the utilization of hollow blocks in housing has, so far, been



106. A.R.P. Block.*



107. Four Brick Slabs.



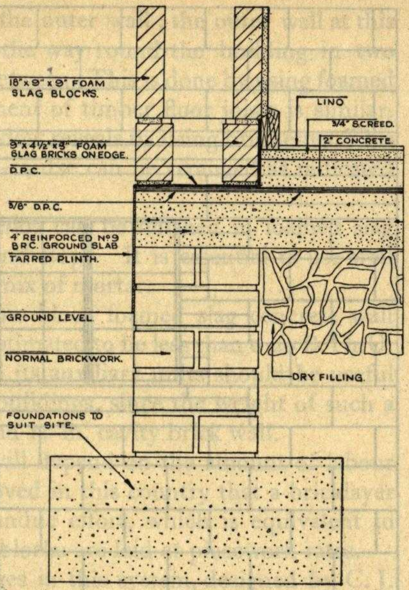
108. Briquettes of standard brick size.

*Figs. 106-113 are reproduced by permission of Mr. M. Gaillai-Hatchard.

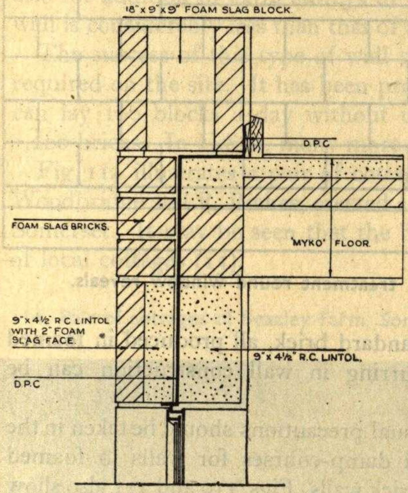
negligible. On the other hand, hollow blocks of 18 in. × 9 in. × 9 in. nominal size in ordinary concrete were used in large quantities during the war as A.R.P. blocks and for various defence purposes. These units weigh between 65 to 70 lb. each. In foamed slag concrete their weight is reduced to 35 to 40 lbs. with the additional advantages of high thermal insulation, freedom from condensation, nailability, superior fire resistance and sound absorption. The industry is well equipped with machinery for the production of such blocks. However, this large unit, which in itself is only suitable for straightforward large surfaces, cannot be subdivided without considerable waste, and would not satisfy requirements at window or door reveals, bays, etc.

According to B.S.834 : 1944, the actual dimensions of the hollow block are $17\frac{5}{8}$ in. × $8\frac{5}{8}$ in. × $8\frac{5}{8}$ in. Such a block (Fig. 106) is equivalent in volume to twelve standard bricks $8\frac{5}{8}$ in. × $4\frac{1}{4}$ in. × $2\frac{5}{8}$ in., including the $\frac{3}{8}$-in. mortar joints (Fig. 108). The block can also be subdivided into three slabs of $17\frac{5}{8}$ in. × $8\frac{5}{8}$ in. × $2\frac{5}{8}$ in., including the $\frac{3}{8}$-in. mortar joints (Fig. 107). Each of these slabs represents the volume of four bricks with $\frac{3}{8}$-in. mortar joints, and therefore the Four Brick Slab is a good name for this unit. With the three types of units, i.e. the A.R.P. block, the Four Brick

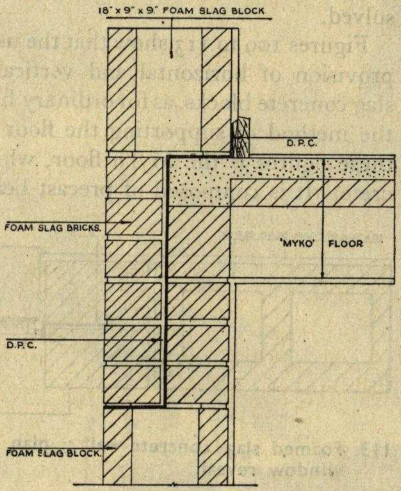
109. Section through foundation and ground floor.



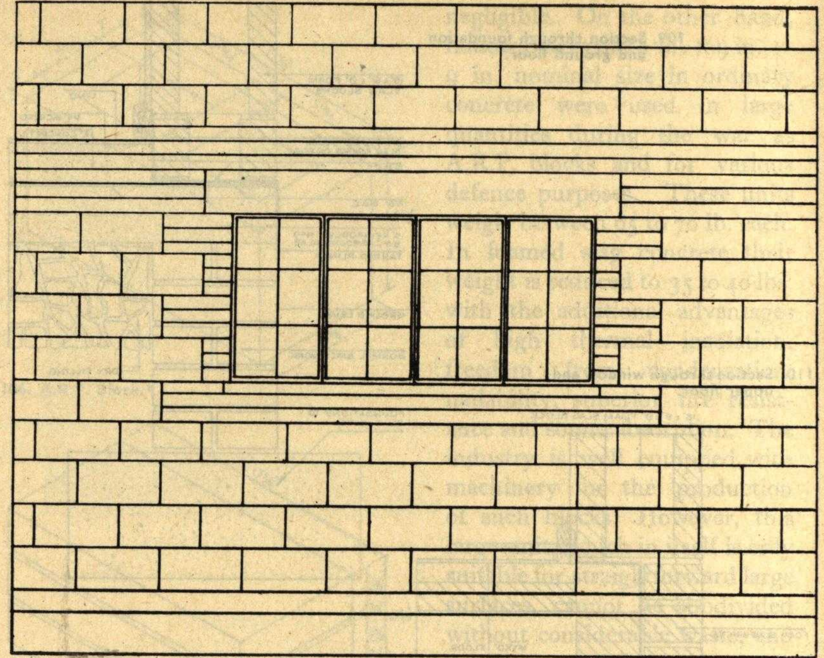
110. Section through window and upper floor.



111. Section through solid wall and upper floor.



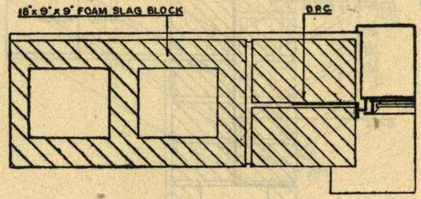
Three Sections showing the damp-proofing precautions for walls in foamed slag concrete blocks.



112. Foamed slag concrete walls : treatment round window reveals.

Slab and the Briquette, equal to a standard brick, all produced in foamed slag concrete, every problem occurring in wall construction can be solved.

Figures 109 to 113 show that the usual precautions should be taken in the provision of horizontal and vertical damp-courses for walls in foamed slag concrete blocks, as for ordinary brick walls. Figs. 110 and 111 also show the method of supporting the floor on the wall. The floor indicated in these figures is the Myko floor, which itself embodies foamed slag concrete. It is composed of precast beams with a high grade concrete core, containing the reinforcement, and a foamed slag concrete casing, precast foamed slag concrete slabs spanning between these beams and forming a permanent shuttering, and an in situ concrete topping which unites the precast beams into a monolithic construction (13) (14). With this floor a bearing



113. Foamed slag concrete wall : plan of window reveal.

is taken at a number of points on the outer wall; the outer wall at this level should therefore be treated all the way round the building in two halves, with a vertical damp-course between. This is done by using foamed slag concrete briquettes. The treatment of timber floor joists is similar.

Fig. 112 shows the treatment of window reveals by using briquettes. This has the advantage that a damp-proof-course can be arranged as indicated in Fig. 113.

The raking top courses of gable ends can be finished in foamed slag briquettes cut to the required size and slope. It is essential to use well matured blocks and a relatively lean mix of mortar.

The thermal conductivity of hollow block foamed slag concrete wall with rendering inside and outside is estimated to be less than 0·20 B.Th.U.

The foamed slag hollow block and its auxiliary units should be useful also for addition of extra storeys to buildings, since the weight of such a wall is considerably less than that of an 11-in. cavity brick wall.

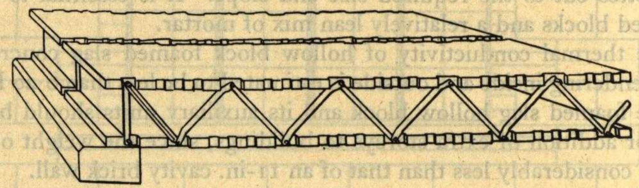
The success of this type of wall will depend on the amount of labour required on the site. It has been proved in this country that a bricklayer can lay 100 blocks a day without undue effort, which is equivalent to 1,200 bricks. In U.S.A. many more blocks are laid at piecework rates.

Fig. 114 illustrates a pair of cottages in this system, designed by C. J. Woodbridge and R. Riches, erected at Beazley Farm, near Timberscombe, Somerset. It may be seen that the building conforms with the character of local cottages (15).

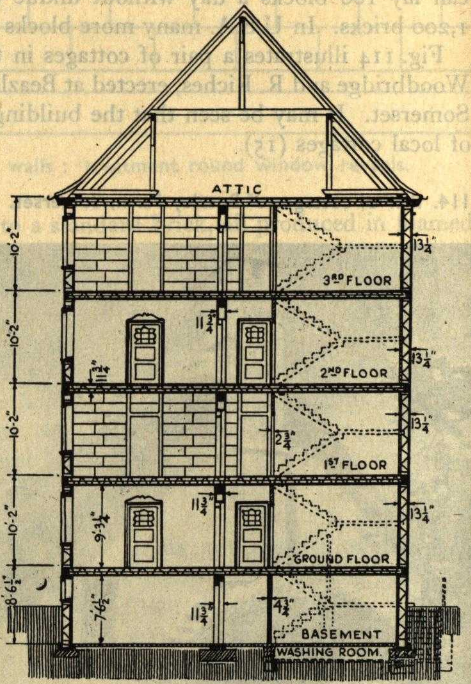
114. Pair of cottages of Beazley Farm, Somerset.

(b) LARGE REINFORCED PRECAST UNITS

The efforts made by Grosvenor Atterbury in U.S.A. and Ernst May, Housing Architect at Frankfurt-on-Main, are mentioned elsewhere in this book. Another system of interest* is that developed by W. Schaefer in Germany some 20 years ago. Schaefer constructed a machine for the mass production of large slabs of lightweight concrete with pre-stressed



115. A Schaefer Unit.

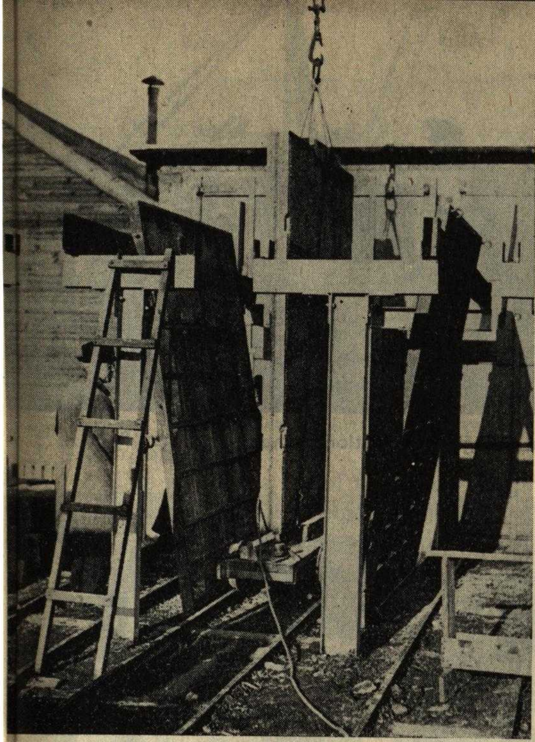


116. Cross-section of a block of flats. Walls and floors formed of Schaefer units.

* This system has particular relevance to the recent pronouncement of the Minister of Health that he intends to encourage the building of multi-storey blocks.

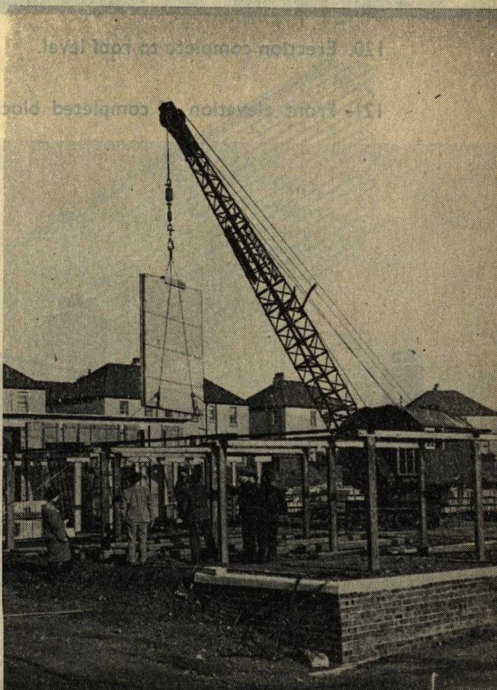
reinforcement (16) and assembled these slabs into units similar to a lattice girder.* The top and bottom member each is formed by a precast slab, 2 to $2\frac{1}{2}$ in. thick and approximately 2 ft. 6 in. wide. The diagonals are in steel, connected with the slabs at both edges (Fig. 115). Such units can be used for walls, floors and flat roofs (Fig. 116). The double skin wall gives a high degree of thermal insulation.

In this country the method of prefabricating large wall units in a factory has been adopted by the Glasgow Corporation (17). It has been developed by J. H. Ferrie, the chief Housing Architect of the Corporation, and W. Kerr.



117. Wall unit ready to be lifted for stacking.

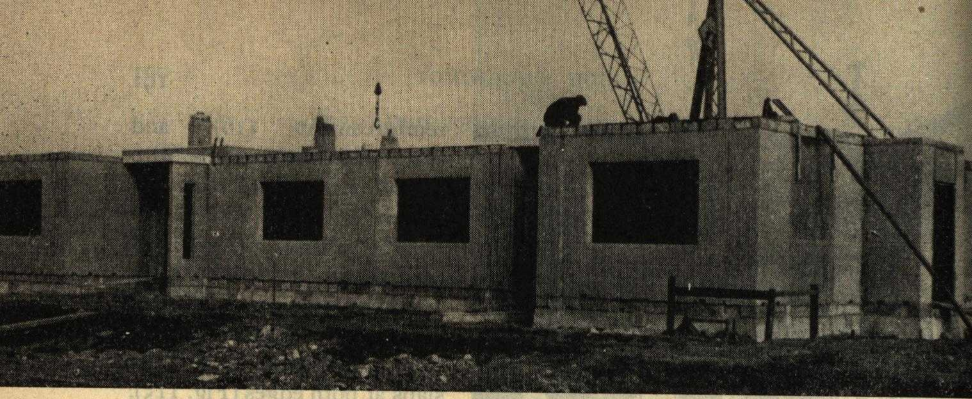
The reinforced foamed slag concrete units, up to a size of 10 ft. by 8 ft. $8\frac{1}{2}$ in., are cast vertically in steel moulds. The panels are matured in a steam chamber from which they are removed on the following day when the moulds are struck and the units lifted and stacked in the yard. (Figs. 117, 118.) The number of moulds is considerably reduced by this process as against manufacture without steam curing, since moulds for one day's output only are required.



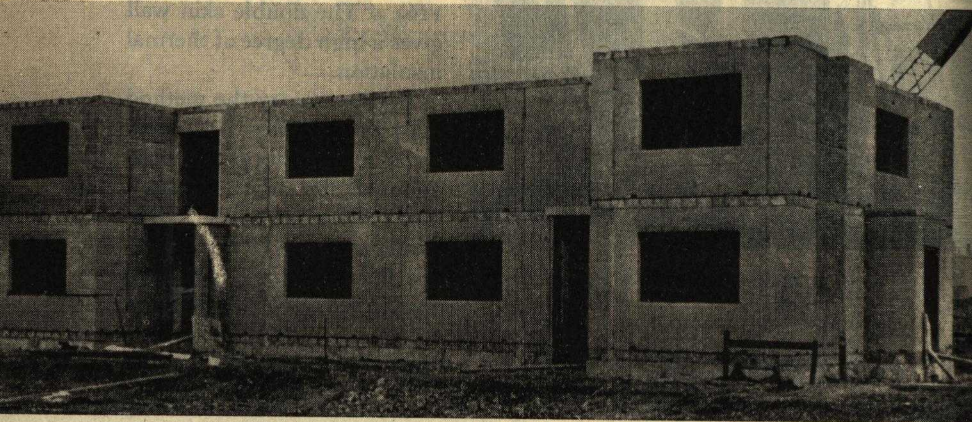
118. A precast wall unit being lifted by a crane for stacking.

*The machine is described in British Patent Specification No. 391320. The process is highly mechanical and the slabs are produced with great precision.

Figs. 117–121 are reproduced by permission of Mr. J. H. Ferrie.

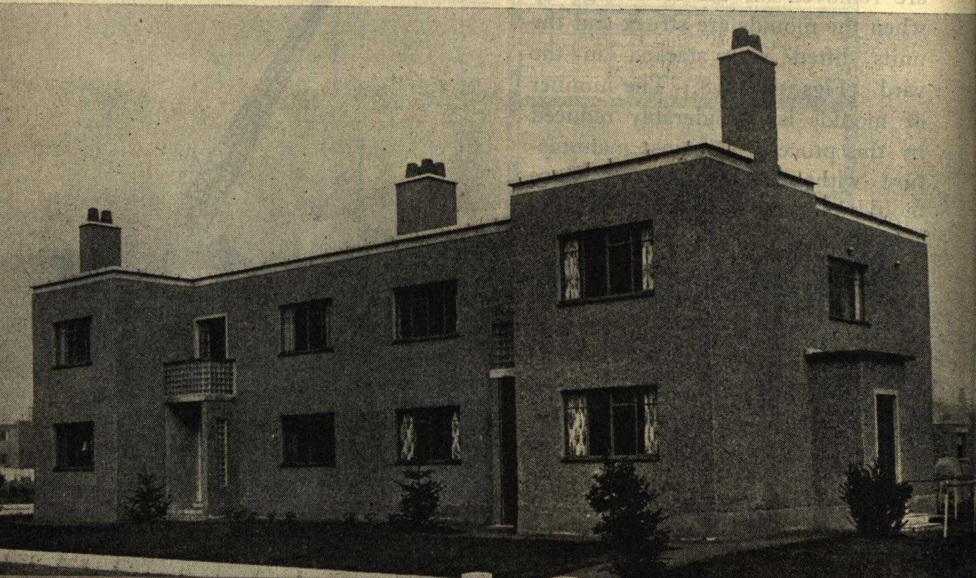


119. Experimental flatted houses in Glasgow. Erection complete to first floor.



120. Erection complete to roof level.

121. Front elevation of completed block.



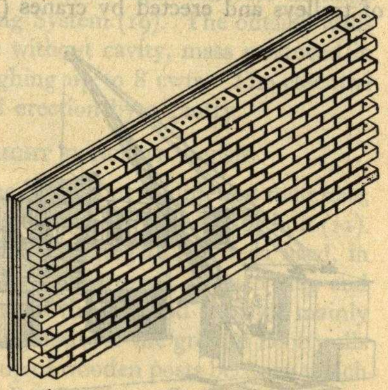
The external walls are only 6 in. thick in one single leaf, the partition walls only 4 in. Elaborate tests have proved that these thicknesses are adequate in a building of two storeys from the point of view of strength. The thermal insulation of the external wall is slightly superior to that of an unventilated 11-in. cavity brick wall. (Heat transmission ·26 B.Th.U. as against ·30). The inner face is free from condensation. With the same internal dimensions the overall area is smaller than that of a traditional brick building, since the walls only occupy a strip of 6 in. width instead of 11 in.

The party wall is arranged in two leaves and reaches the standard of sound insulation suggested in (3), which is higher than that of the usual 9-in. brick wall.

The wall units are of full storey height. They are erected by cranes. Joints at corners are avoided by the use of L- and T-shaped units, which increase stability during erection and ensure easy plumbing. Window and door openings are provided for in the casting, the bedding and setting of cills and lintols are avoided. The chimney breasts are also built in precast foamed slag concrete units, the flues being formed by fire clay vent lining.

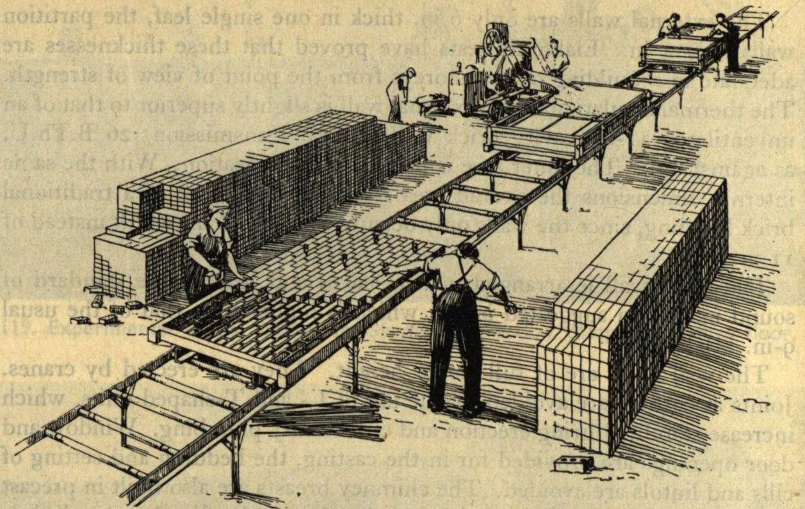
Fig. 119 shows the erection, completed up to first floor, Fig. 120 the erection completed up to roof, Fig. 121 a completed block of four flats. It may be seen from the last figure that the completed block does not differ in appearance from traditional brick buildings with the same surface treatment.

Another method of using large precast units is Simplified Brick Construction (18). The walls are made up of large prefabricated panels with a 4½-in. brick external face, 2 in. cavity and a 4-in. internal skin of lightweight concrete (Fig. 122).* The inner skin is tied to the outer skin, and both are produced in one continuous operation by a standard unit of plant, erected in a central position on the site (Fig. 123). Bricks are placed in a grid; reinforcing rods, wall ties and sides of pallets are placed in position, then grout is run over the surface of the bricks. The joints are filled by vibration. The reinforced inner skin of lightweight concrete is poured on steel shuttering which is placed on top of the brick panel on blocking pieces to form a cavity. After the



122. Prefabricated panel in Simplified Brick Construction.

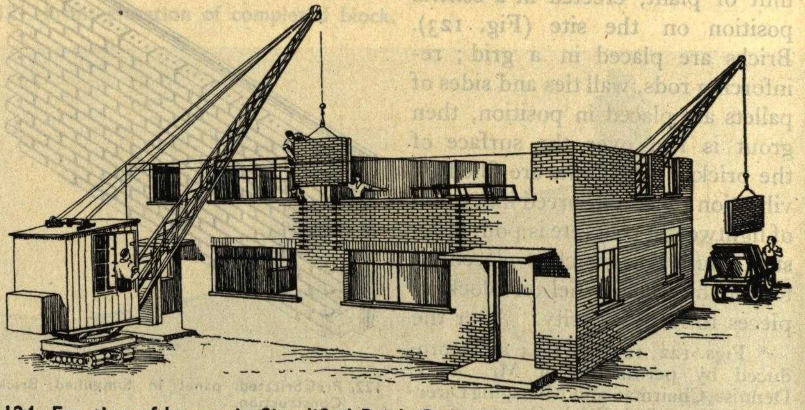
* Figs. 122, 123 and 124 are reproduced by permission of Mr. A. J. Denniss, Chairman and Managing Director of Simplified Brick Constructions, Ltd.



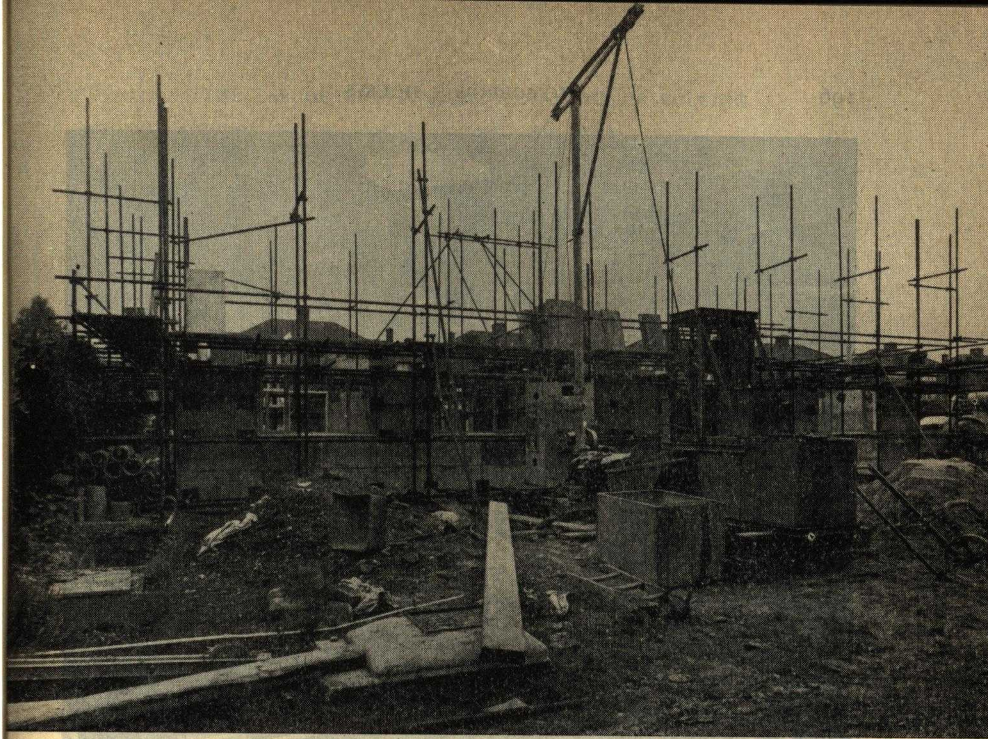
123. Production line for Simplified Brick units ; this consists of a roller runway carrying a series of pallets into which are placed the materials necessary for the manufacture of each individual unit.

manufacture of each individual unit, the pallet is run into a track where it can stand for 24 hours during the initial setting of the cement. After this period the units are removed from the pallets and set aside for final maturing. The flues, chimney breasts and partitions are formed in special pallets. Load-bearing partitions are 4 in. wide, others 3 or 2 in. During the manufacture of these sections, the electric conduits and switch boxes are cast into the moulds.

The matured units are taken to the individual building sites on a series of trolleys and erected by cranes (Fig. 124).



124. Erection of houses in Simplified Brick Construction.



125. Pair of experimental houses at Canon's Park, Edgware*.

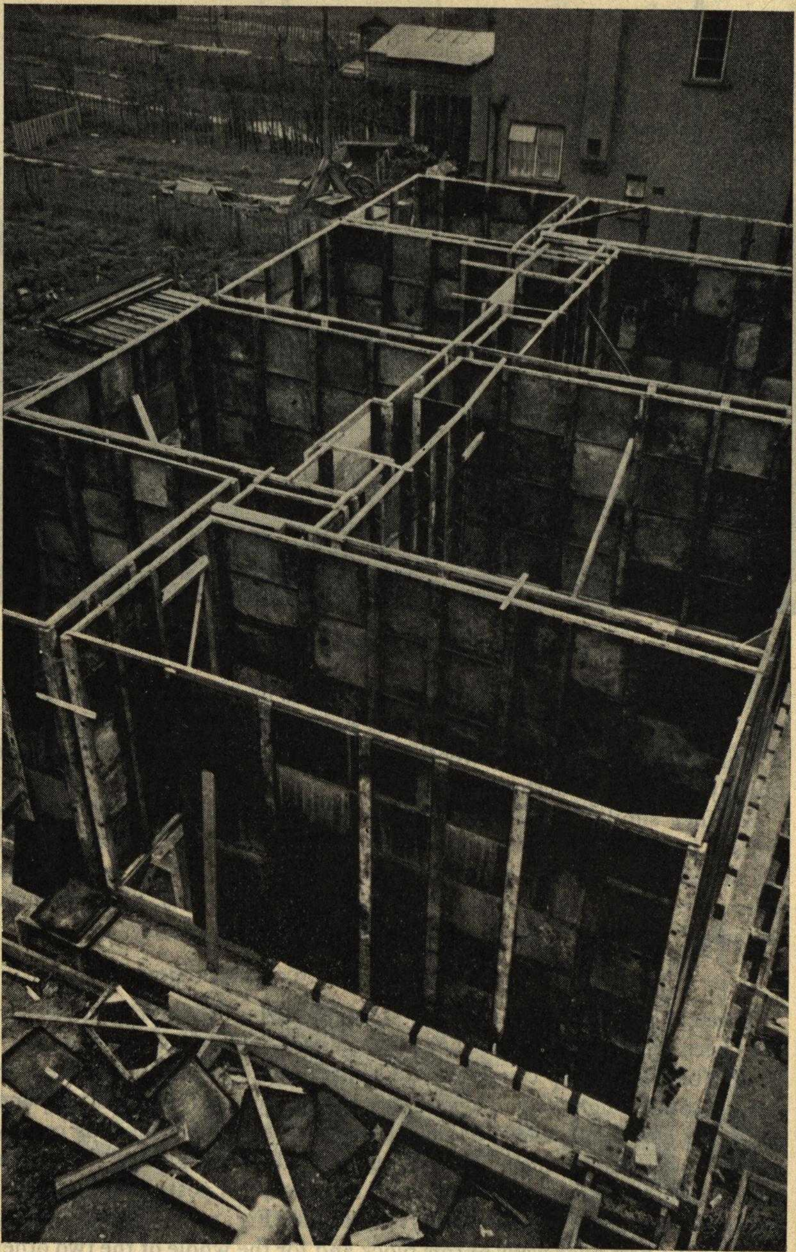
The manufacture and erection of the units is based on a 24 hours cycle. One unit plant can produce two houses a day, i.e. 500 houses in a year. By this method houses of conventional appearance are produced, but more quickly than has hitherto been done.

Another similar method of the use of lightweight concrete in large units is incorporated in Smith's Building System (19). The outside walls are of brick-faced lightweight concrete without cavity, mass produced in sizes up to 7 ft. by 2 ft. 6 in. and weighing up to 8 cwts. The essential feature of this system is the method of erection by a gantry.

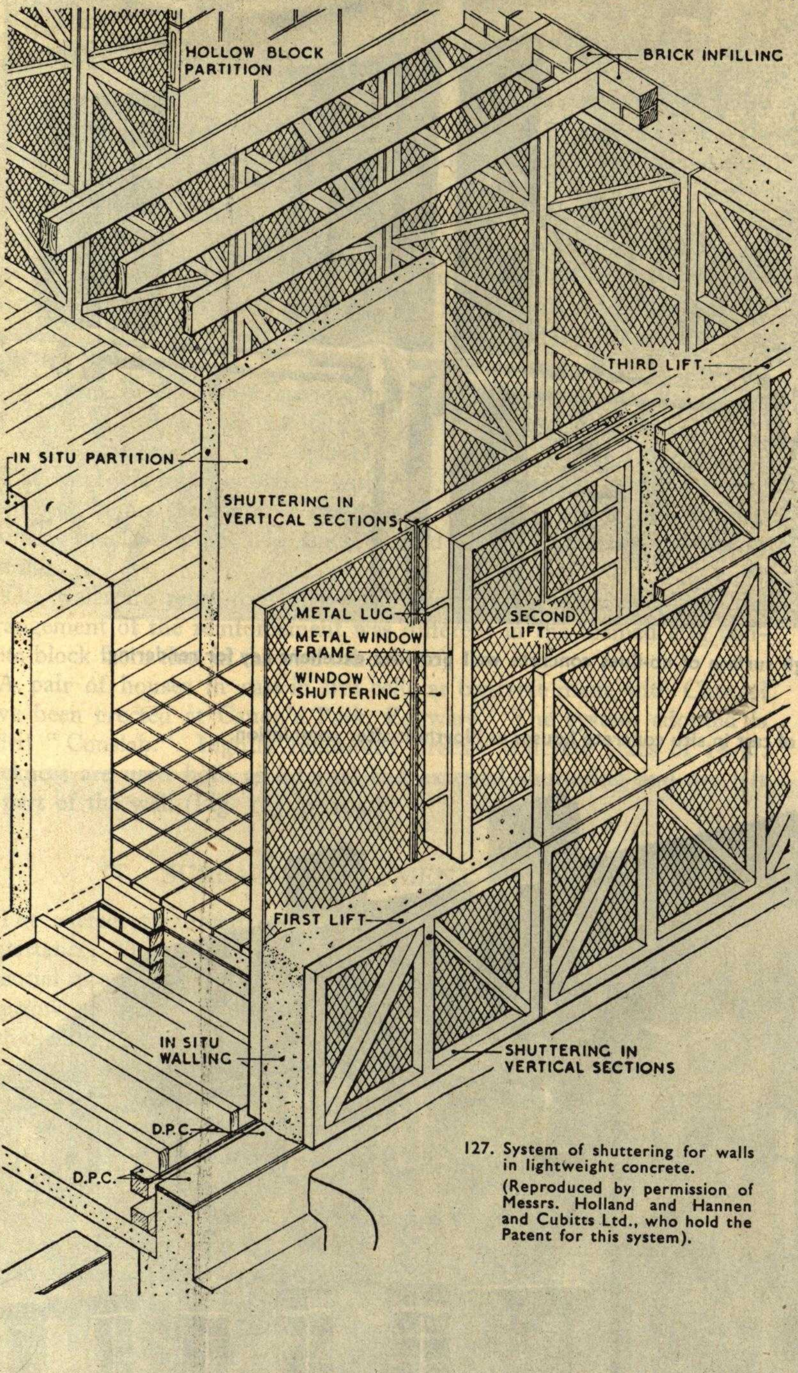
(c) CAST IN SITU LIGHTWEIGHT CONCRETE HOUSES

Three blocks of houses, with the same layout but in different materials, have been built by this method by the Ministry of Works at Northolt (11). In one block no-fines concrete with clinker aggregate has been used, in the two others lightweight aggregates have been used, foamed slag and expanded clay respectively. The success of this method depends mainly on the type of shuttering. The shuttering used for the ground floor walls of the no-fines concrete house was built up of wooden posts between which flat steel shuttering was placed (System Pond) (Fig. 126). The shuttering used for the first floor walls of this block and for the whole of the two other

* Published by permission of Major L. Shingleton.

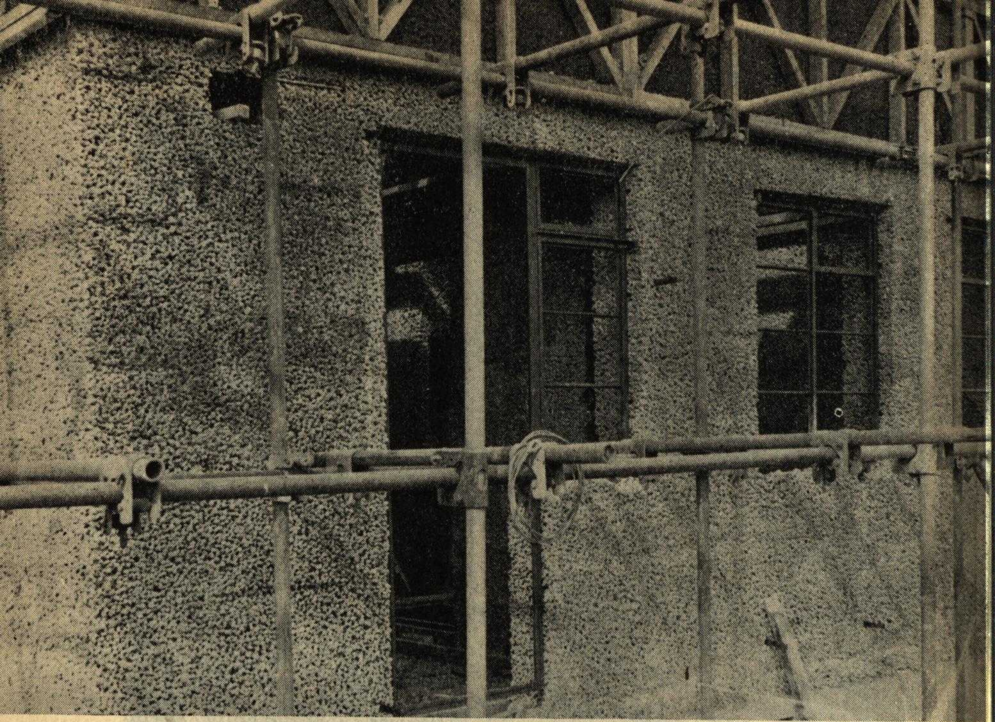


126. Shuttering for the ground floor walls of the no-fines concrete house at Northolt.



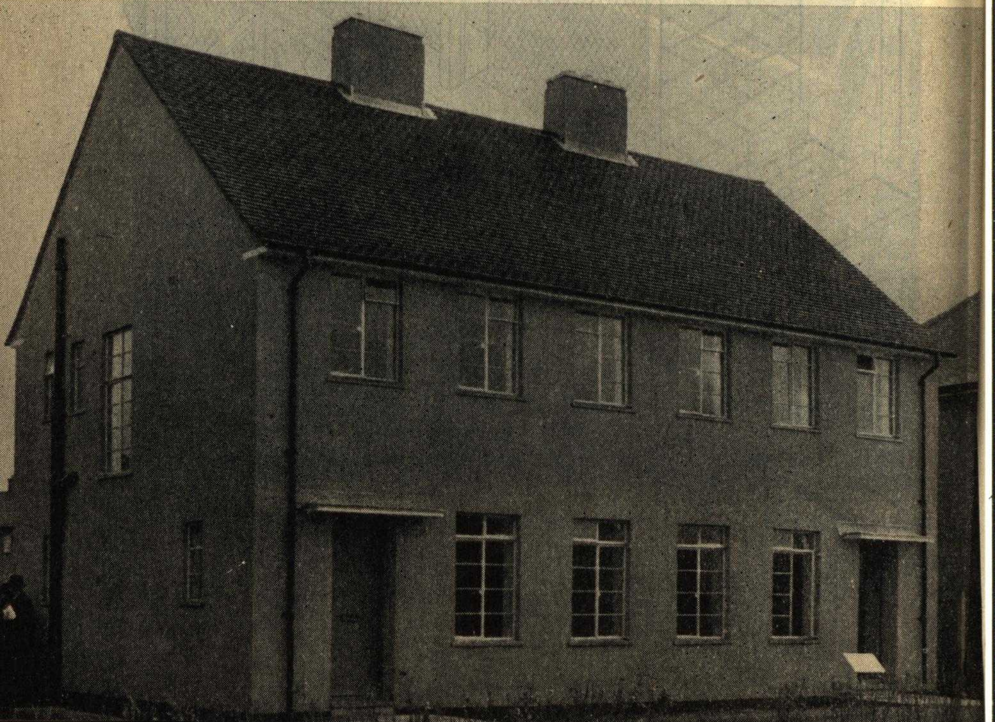
127. System of shuttering for walls in lightweight concrete.

(Reproduced by permission of Messrs. Holland and Hannen and Cubitts Ltd., who hold the Patent for this system).



128. Rough surface of no-fines concrete wall provides excellent key for rendering.

129. Pair of cast in situ concrete houses at Northolt after completion.



blocks was built up in sections in the form of open timber frames strongly braced and faced on one side with small-mesh expanded metal (Fig. 127). The concrete mix was of such consistency that none of it seeped away through the meshes of expanded metal, and the latter, when removed, left markings on the surface of the wall which formed a key for the subsequent rendering.

The external walls of the no-fines concrete blocks are 12 in. thick, these of the blocks with lightweight aggregates are 8 in. The party walls are 8 in. thick, the load bearing partitions 4 in. thick in all three blocks. In the partitions of the no-fines concrete block natural ballast has been used as aggregate. The calculated heat transmittance values of the external walls are as follows:

12-in. no-fines concrete in clinker aggregate	·23 B.Th.U.
8 ,, foamed slag concrete	·16 ,,
8 ,, expanded clay concrete	·16–·20 ,,

The steel windows, complete with lugs, were fixed in position to the shuttering before the concrete was poured. The flues are of 9-in. internal diameter fireclay piping, 1-in. thick, jointed in fireclay mortar, and cast in position.

The walls are reinforced above the window and door openings, the arrangement of the reinforcement was different in the foamed slag concrete block from that in the two others (20).

A pair of houses in cast in situ cellular concrete made with Cheecol have been erected at Canon's Park, Edgware. The system adopted is called "Conslab." Lightly reinforced precast concrete slabs of $1\frac{1}{2}$-in. thickness are used both as internal and external shuttering and are left as part of the wall (Fig. 125, p. 195.)

IV. SURFACE TREATMENT OF WALLS

The surface treatment of lightweight concrete walls is of particular importance. There are two schools of thought. According to the one, it is essential to apply a dense rendering. This method has been adopted in Glasgow, where the walls of the completed building have been roughcast, with cement rendering on the outside and plastered on the inside. According to the other (and this is also the view of the writer), the use of a waterproof rendering is unnecessary and, in fact, may be dangerous. If cracks occur in such a rendering, moisture may penetrate into the wall. Since it cannot find its way out it will cause dampness on the inner surface. It should be remembered, as was pointed out on p. 183, that lightweight concrete is of honeycombed nature and is not hygroscopic like brickwork. Consequently, from the point of view of keeping the inner surface of the wall dry, no rendering would be required. This has been proved by various experimental buildings which stood up against rain very well although their

walls are only 4 in. thick. For example, an office, built for the purpose of demonstration at Scunthorpe in 1935, has external walls constructed of 18 in. × 9 in. × 4 in. foamed slag concrete slabs ; the external joints were pointed but the whole outer surface was left unrendered. The inner surface received one coat of plaster of Paris, used intentionally as a serious test, because plaster of Paris would deteriorate if subjected to moisture. There is no evidence whatever of any moisture penetrating, although the building has now been exposed to frost and driving rain throughout ten winters. On the other hand, the appearance of lightweight concrete is not satisfactory from the aesthetic point of view, and for this reason a rendering is necessary. It should however be of the " breathing " type which does not prevent the penetration of rain and, at the same time, allows the escape of moisture.

A comparatively cheap and effective method of external rendering is the following :

The first coat, $\frac{3}{8}$-in. to $\frac{1}{2}$-in. thick, should consist of:

1 volume Portland cement,
3 volumes finely ground hydrated lime (white),
9 volumes foamed slag fines ($\frac{1}{8}$-in. to dust).

The finishing coat is a slung rough cast applied while the first coat is still wet. The mix of this second coat is :

1 volume Portland cement,
3 volumes finely ground hydrated lime,
9 volumes foamed slag aggregate, consisting of a mixture of 2 volumes coarse foamed slag ($\frac{3}{4}$-in. to $\frac{1}{8}$-in. or $\frac{1}{2}$-in. to $\frac{1}{8}$-in.) with 1 volume foamed slag fines ($\frac{1}{8}$-in. to dust).

For the internal rendering the same mixture as suggested for the first coat of the external rendering may be applied in one or two coats.

Of course, any open textured rendering may be adopted, e.g. 1 volume Portland cement : 2 volumes finely ground hydrated lime : 9 volumes washed sand.

V. APPLICATION IN FLOORS AND ROOFS

Although the primary object of this article was to describe the application of lightweight concrete in walls, a short reference to its use in floors and roofs may be of interest.

Lightweight concrete may be used in floors and roofs both as structural and as non-structural material. As structural material it is very popular in the U.S.A., whereas in this country it has so far been confined mainly to non-structural parts of the building.

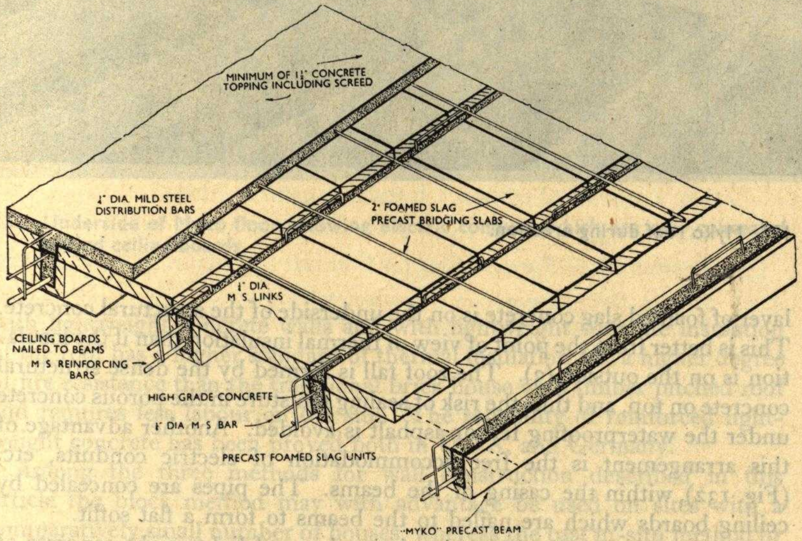
One example of precast reinforced lightweight concrete floor and roof units is the Schaefer System already mentioned on p. 190. In the U.S.A. pre-stressed beams of an I-section are commonly used. In-situ lightweight

concrete with reinforcement has been used successfully in both these countries with all the advantages against ordinary heavy concrete as described earlier in this section.

An example of the application of structural lightweight concrete in this country is the roof of the Braithwaite House* (21) which is made of reinforced cellular concrete of 2½ in. thickness.

The most frequent use of lightweight concrete in floors and roofs as non-structural material is either in the form of precast hollow blocks or slabs, or as in-situ screed on concrete roofs to form a watershed and to provide thermal insulation. There are a number of systems on the British market incorporating precast lightweight concrete units as non-structural members.

If lightweight concrete is used as roof screed, great care must be taken to apply the waterproofing felt or asphalt at a time when the screed is dry.



130. Isometric view of the Myko floor.

This may be difficult in certain districts during the best part of the year, since the honeycombed screed on a horizontal surface gets saturated with water after every rain. If the roofing felt is applied in this state, the moisture which cannot evaporate penetrates to the soffit of the concrete roof.

A particular application of non-structural lightweight concrete is incorporated in the Myko System of shutterless floors and roofs (p. 188). Fig. 130 shows the details of the system and is self-explanatory, Fig. 131 shows a Myko roof during erection ; on the roof in the background the screed has been completed. As may be seen from these two figures, the

* See pp. 164-165, 221-224.

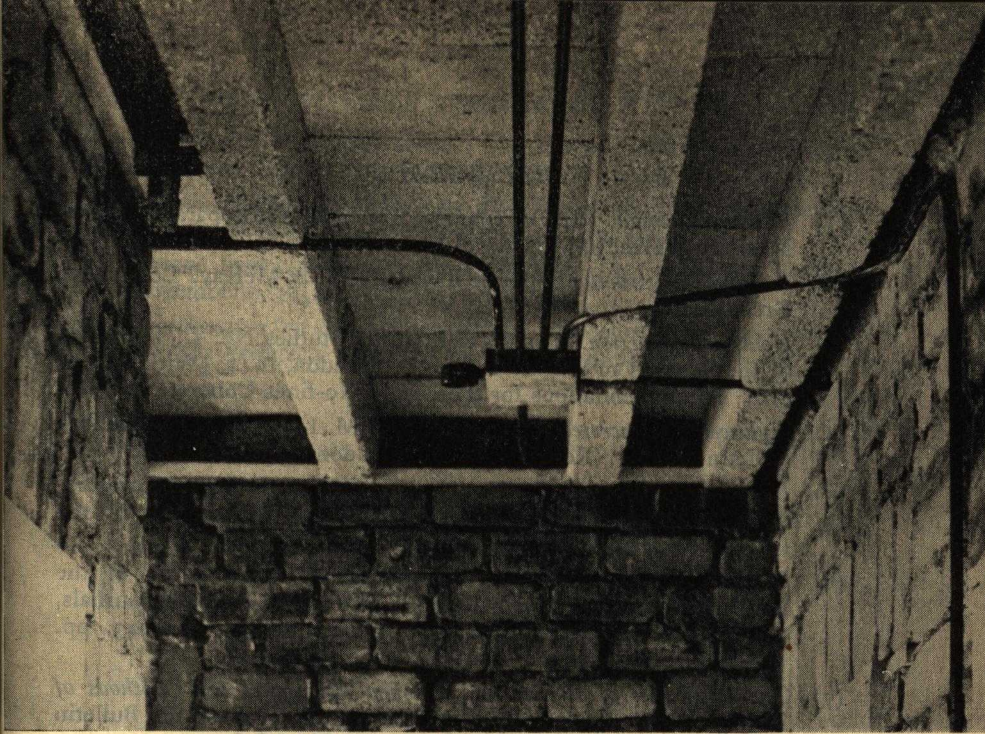
131. Myko roof during erection.

layer of foamed slag concrete is on the underside of the structural concrete. This is better from the point of view of thermal insulation than if the insulation is on the outside (3). The roof fall is formed by the dense structural concrete on top, and thus the risk of sealing moisture in the porous concrete under the waterproofing felt or asphalt is avoided. Another advantage of this arrangement is the free accommodation of electric conduits, etc. (Fig. 132), within the casing of the beams. The pipes are concealed by ceiling boards which are nailed to the beams to form a flat soffit.

A flat concrete roof with an insulating layer of lightweight concrete of 2-in. minimum thickness has a much higher standard of thermal insulation than a traditional timber pitched roof. According to (3), the heat transmittance of a timber pitched roof, tiled on battens and felted, with plaster ceiling is ·43 B.Th.U. as against a desirable maximum of ·30. A Myko roof with flat soffit has a maximum heat transmission of ·28 B.Th.U.

VI. CONCLUSIONS

Lightweight concrete may be looked upon not as a substitute, but as an alternative, not only to brickwork, but also to timber. In fact, a house



132. Underside of Myko floor, showing electric conduits which are later concealed behind ceiling boards.

with lightweight concrete walls and with lightweight concrete insulation of the roof has a higher standard of thermal insulation and a higher degree of fire resistance than the traditional brick house with timber pitched roof and requires less labour on the site. The reliability of reinforced lightweight concrete has been proved both in U.S.A. and Germany.

Among the three methods for wall construction described in this article the block method may with advantage be used on sites with a comparatively small number of houses, whereas the cast in-situ method or Simplified Brick Construction are applicable to schemes comprising many hundreds of houses. The method adopted by Glasgow Corporation can only be used by large municipal authorities.

It is reasonable to expect that the post-war period will see a great development in the use of lightweight concrete in housing in this country, provided the industry will be able to organize the production and supply of suitable lightweight aggregates to meet the demand.

If this one condition is fulfilled, we may expect to see the widespread adoption of lightweight concrete, not only in the immediate period of emergency but also as a permanent addition to our range of building techniques.

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SECTION VII

THE "A.I.R.O.H. HOUSE"

SEVERAL of the temporary prefabricated bungalow types so far developed have been designed by engineers experienced in the use of particular materials. Thus the Portal House, the first type to receive wide publicity, was designed in consultation with the experts from selected firms manufacturing motorcar bodies and other pressed steel products.

The design of the A.I.R.O.H. House is the result of a similar process, though the manner of setting about it has probably been more rigorously planned. The whole concept of the A.I.R.O.H. is based on the suitability for house building of methods of construction and assembly developed in the course of the aircraft production programme.

This background is immediately apparent on inspection. Not only are the main materials—aluminium alloy extruded section and sheet —the materials of most modern aircraft. Even more characteristic than this, the whole method of assembly is based upon aircraft production practice. The final assembly is done with Root joints, such as join wings to fuselage ; wiring of each section is done separately and the circuits are closed by means of plug and socket attachments. It is in such details as these that we see the inspiration of the A.I.R.O.H. House.

Some will complain that the result has little in its appearance to recall the taut lines of the Spitfire or of the Beaufighter. It must be conceded that the design has not yet in outward expression fully found itself. That is not the point. What is much more significant is that the minds which have created the modern aircraft have turned their attention to the solution of an almost equally urgent problem. In doing so they have produced a design which is more completely prefabricated than any which has so far appeared. And although their initial design is a response to the existing surplus of Secondary Strong Alloy and to the overwhelming current demand for houses even of a temporary standard, the substance of the method may equally well be applied in the future to the provision of permanent homes.

THE "A.I.R.O.H." HOUSE

By W. GREVILLE COLLINS

GENERAL NARRATIVE

DURING the early years of the war, a small group of Industrialists, appreciating the serious problems of the housing shortage and foreseeing the redundancy of labour and factory space in the Aircraft industry which would follow deflation in war production, conceived the basic idea of a completely factory-made house which could be built on assembly lines and would reduce site labour to the minimum.

Design was commenced by " The Aircraft Industries Research Organisation on Housing "—a non-profit making body—on a " space-enclosing unit," using factory capacity to its utmost and calling on the full resources of war-time experience in technical and scientific development.

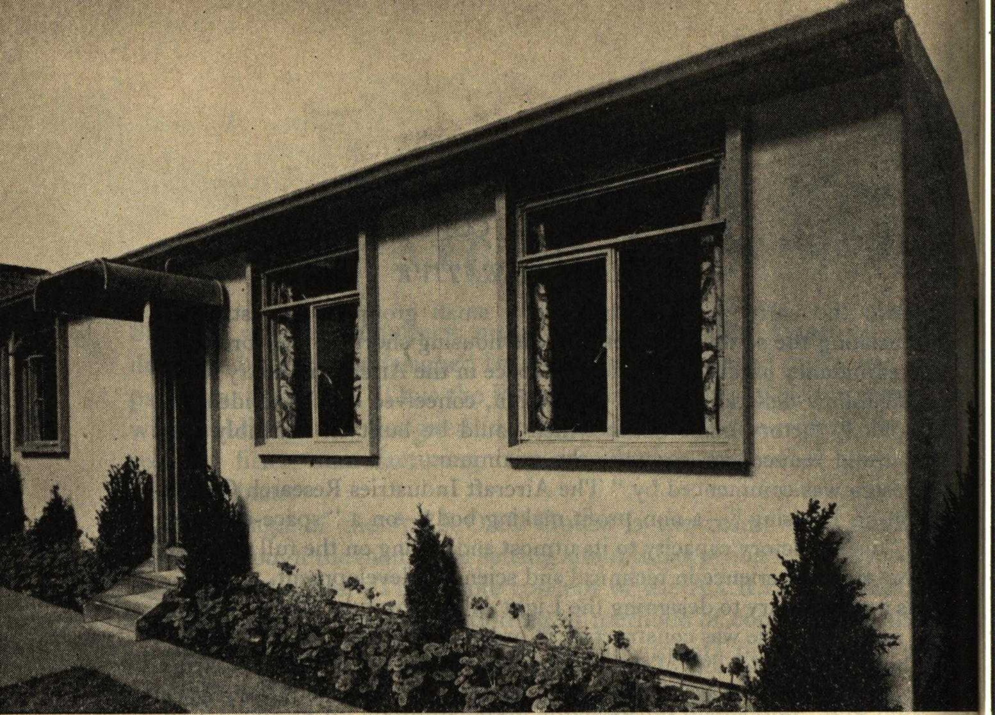
As a preliminary to designing the Light Alloy prototype model, a timber and asbestos house was constructed, in order to prove the design theory of the basic transportability of the structure and to test the production theme. It was established that, within the basic idea, an Aircraft factory could productionise the assembly of house sections in timber, light alloy or any combination of suitable materials.

Sir Stafford Cripps, then Minister of Aircraft Production, recognised the possibilities of the scheme as a solution to the problems mentioned above. Knowing also that there was likely to be an excess of light alloys at the end of hostilities which might be made available for inclusion in the houses at the cost of its reconversion to secondary sheet and section, he gave an order to build an aluminium alloy prototype.

A Technical and Design Sub-Committee was appointed, comprising Design and Production engineers from the leading Aircraft and subsidiary firms, with an experienced House-builder as Chairman, with the object of constructing a prototype, the design of which would fulfil, *but not excel*, the standards demonstrated in the Portal Temporary bungalow.

The Light Alloy prototype was then constructed at the Bristol Aeroplane Company's factory at Weston-super-Mare and delivered, by road, fully fabricated, to the London site in four sections—22 ft. 6 in. × 7 ft. 6 in. each—painted, wired and plumbed. The whole house weighed less than ten tons. Transport costs should, therefore, be covered by normal return journeys of four 5-ton long wheel-based lorries.

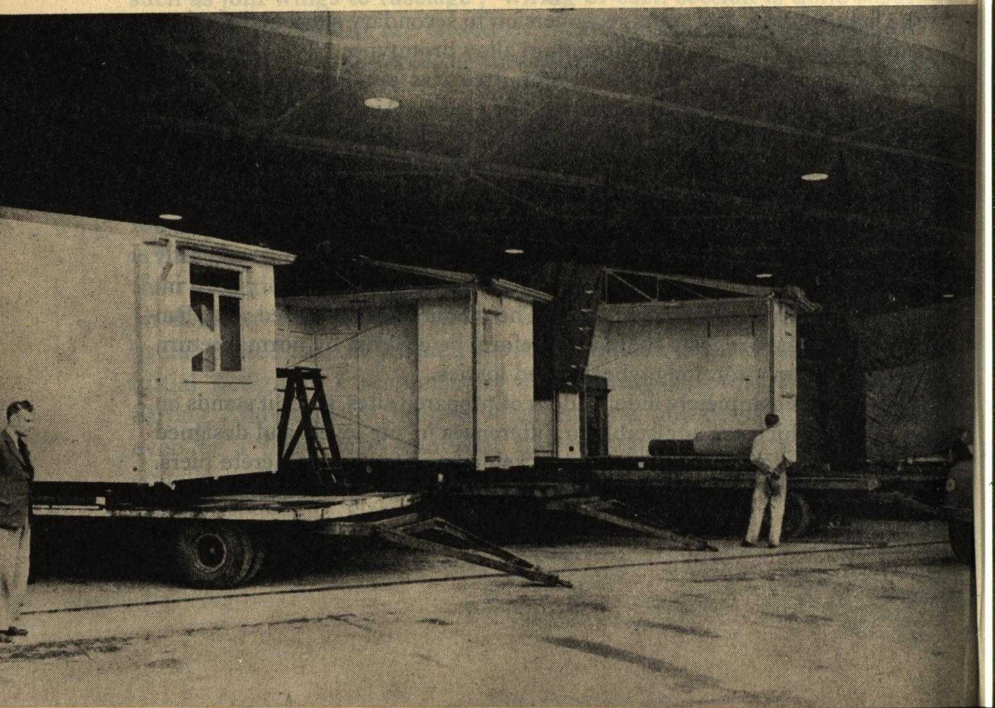
The house is completely independent of prepared sites, since it stands on screw jacks, which are adjustable to differences in site levels and designed to stand on paving slabs, concrete blocks or free-standing concrete piers. Should settlement occur at any point the jacks can be adjusted from inside the house.



133. Front elevation.

THE A.I.R.O.H. HOUSE.

134. House units loaded on trailers ready for delivery to site.



Assembly on site is confined to positioning the four sections (which are fastened together by Root joints and pins, of the type used to fasten the wing to an aircraft body) and fixing the external and internal cover strips. Inter-section connections of the electrical circuit are made with a plug and socket attachment.

The only building labour required is for the laying of sewers.

Site erection can be reduced to 20 man-hours including drainage and service connections.

It should be stressed that the A.I.R.O.H. idea of construction lends itself readily to two-storey permanent housing. The prototype evolved is not, therefore, in itself of such significance as is the general theme of construction and the methods employed. It may also be noted that the A.I.R.O.H. house is 100 % salvageable and is mobile. Heat and sound insulation to any required standards can be achieved by the scientific use of the right materials.

DESIGN—TERMS OF REFERENCE

The design is governed by the limitations of the space-enclosing method, and the overall sizes of the sections are limited by transportability, since, while there are few restrictions as to length, 7 ft. 6 in. is the maximum width allowable for road transport. The kitchen and bathroom, stove unit, flue and water tanks are grouped in one unit for ease of site connections. The lay-out of internal partitions is arranged to clear site joints in order to give access to site connections.

In the preliminary investigation by the Light Metals Control in September, 1944, it was decided that, for housing of this type, aluminium had positive advantages over other available materials ; that aluminium is technically suitable and easily produced in the extrusions, drawn sections and sheet form in which it is required, without expensive dies or tooling up ; and that the factory production was available and easily switched from plane to house production.

Aluminium at 170 lbs./ cu. ft. is about one-third the weight of sheet zinc and copper and one-quarter the weight of lead. Its lightness reduces structural weight, enables easy handling of components and simplifies erection of the A.I.R.O.H. system.

However, in order to reduce the number of sub-assemblies and to facilitate " line production " it was decided to use aluminium only where it could be justified structurally.

MATERIALS

Aluminium

The structural framework is of aluminium alloys. The outer cladding and roof is of sheet aluminium, but, of course, other materials in supply can be used.

The following is an extract from the Report of the Light Metal Control:

"The physical properties of importance in designing for Secondary Aluminium are :—

Specific Gravity	2·75 (average).
Young's Modulus of Elasticity ..	$10 \cdot 0 \times 10^6$ lbs./sq. in.
Coefficient of Linear Expansion ..	$22\text{–}23 \times 10^6$ %

As the modulus of elasticity is approximately only one-third that of steel for equivalent rigidity, a larger moment of inertia of section is required than in steel. Depending on the factor of safety provided for steel sheet, it may be necessary to have a slightly thicker gauge in aluminium or, alternatively, increased ribbing or additional staying. On the other hand, the low modulus of elasticity of aluminium minimises the effect of impact stresses."

Extrusions

All extrusions are of Secondary Strong Alloy and all sheet of Clad Secondary Strong Alloy to the following specification :

2% Proof Stress	13/15 tons/sq. in.
Ultimate Stress	22 to 24 tons/sq. in.
Elongation on 2-in. gauge length ..	12 to 15%.

Although normal commercial lengths for extrusions are 12 ft., larger lengths are easily produced and, where necessary, the whole of the 22 ft. 6 in. depth of the house is produced from a single extrusion.

Sheet

This is normally supplied in standard sizes of 12 ft. × 4 ft., but for the purposes of house production suitable widths are rolled so that no waste is incurred other than the bare cutting margins.

The decision to use alternative materials in juxtaposition with aluminium creates an electrolytic problem. Great care has to be taken where bimetallic joints are necessary, non-water absorption bushes or packings being inserted between the metals, and the adjoining timber treated.

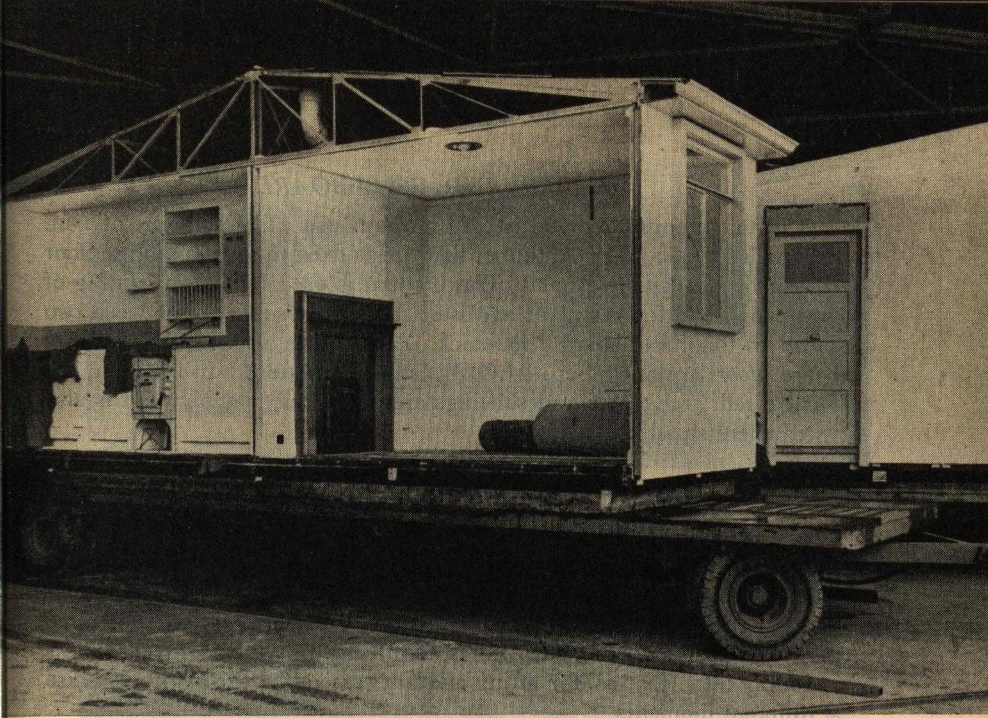
Windows

The windows, supplied complete with all fittings and furniture, are of secondary cast aluminium alloy.

Jointing

Aluminium can be jointed at the factory by mechanised methods, e.g., riveting or bolting, by gas, electric arc or spot welding or by aluminium brazing. Soft soldering is not recommended for housing and only mechanical methods are used in the factory production.

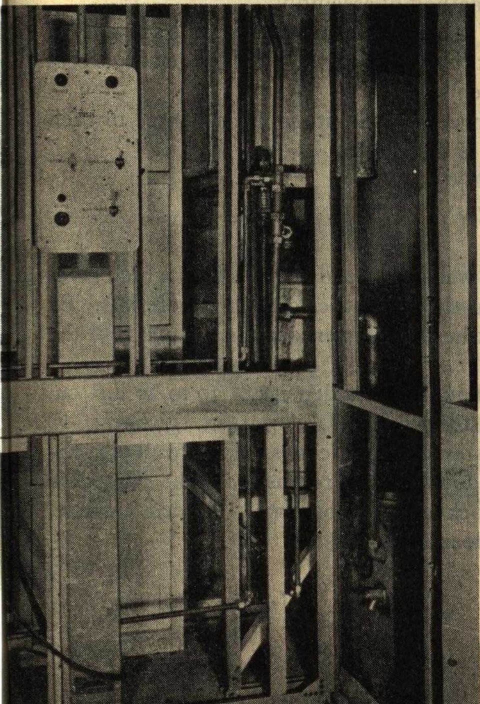
All forms of rivet are available in the alloy recommended for this purpose and are driven cold. The use of aluminium for nuts, bolts and screws is not recommended, except for decorative applications ; these items should be in iron or steel, which should be cadmium plated, sheradised or galvanised ; copper or copper-rich alloys should not be used.

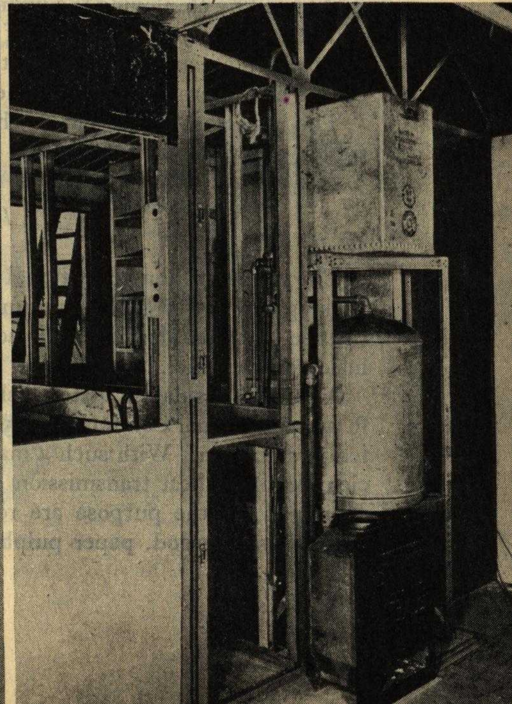


135. Complete Kitchen-Bathroom unit ready for dispatch.

THE A.I.R.O.H. HOUSE.

136. Built in plumbing and electrical gear. 137. Hot and cold water system.





TIMBER AND WALLBOARD

A certain amount of wood is used in the house. The *floors* are of 1-in. deal nailed to 2 in. × 3 in. timber floor joists fixed to the aluminium floor chassis by brackets and bolts. Plasterboard is used for internal lining of wall panels and for partitions and is of aerated gypsum core between two sheets of tough millboard $\frac{3}{4}$ in. thick. *Ceilings* are of $\frac{5}{8}$ in. Tentest fibre board, *doors* are of timber—M.O.W. Standard pattern. In addition, the picture rail, architraves and skirtings are of timber, and plywood is also used where suitable.

STRUCTURES AND ELEMENTS

The structure is founded upon a chassis which forms the floor and carries the bodywork of the house. To lighten the sections of the floor chassis, the deflection is transferred to the roof trusses through the framework of the external wall panels and through the internal central spinal partitions ; thus use is made of the beam formed by the roof truss. This is doubly important as, for lifting and final assembly, the load points are at different moments.

The weathering skin is of 20 gauge sheet aluminium alloy and is riveted to the structural frames and " stuck " to the insulate with bitumastic adhesive.

Extrusive and rolled sections of light alloy are joined by means of pressed gussets and cast brackets. Greater rigidity of the finished product is obtained by employing the jig method of assembly.

The jacking system consists of a bridge beam with central screw-type jacks which are so positioned that, by the removal of a floor-board, access can be had internally for adjustment.

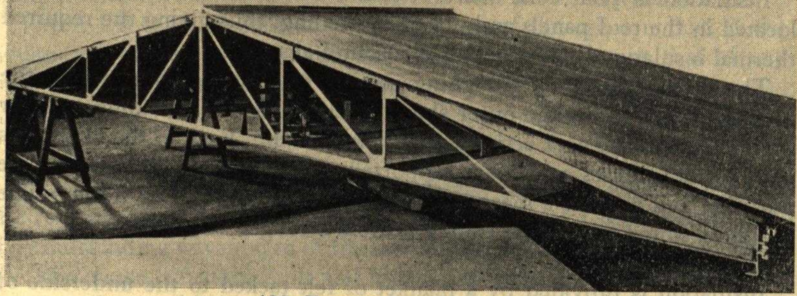
The house has fifteen jacks—three to each site joint and three to each gable—on which the total weight is distributed.

HEAT INSULATION

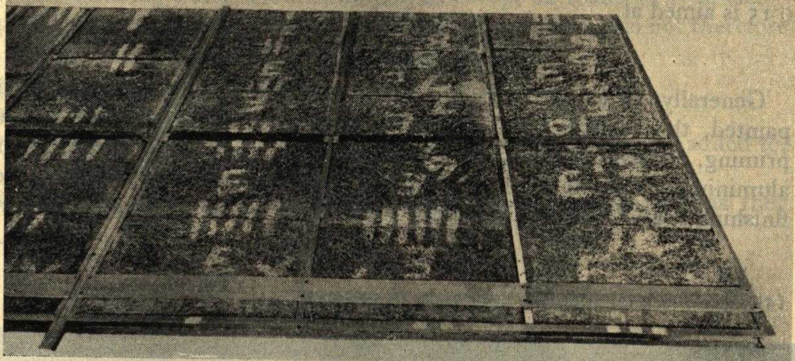
Wall

The insulator filling in external walls can be of any material which gives backing support to the aluminium sheet or other cladding materials. By the use of a suitable bitumastic adhesive, plasterboard is " stuck " to the inside of the panel.

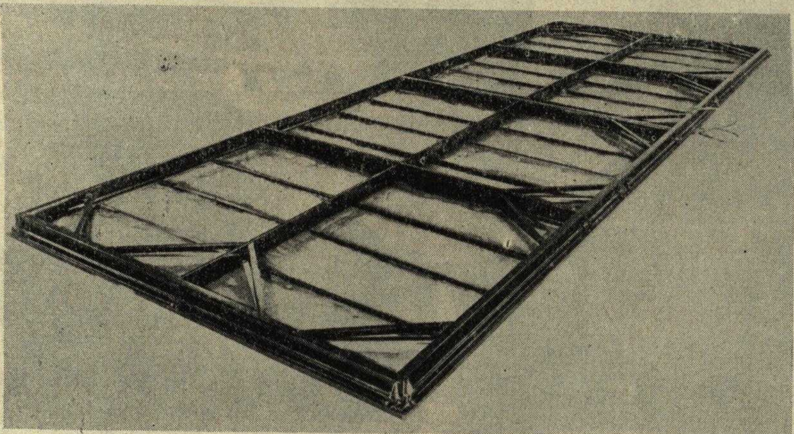
A suitable insulating material should have a density of 20 to 30 lbs./cu. ft. and a Thermal Conductivity ·5 to ·7 B.Th.U.'s·sq. ft./in. thickness/°F. temp. diff./hour. With such a material, the thickness of the wall is sufficient to bring heat transmission down to the requisite level. Materials envisaged for the purpose are rock cork, wood wool, foamed cement, bonded waste-wood, paper pulpboards, etc.



138. Truss and roof assembly.



139. Wall panel showing insulating infill.



140. Underside of floor chassis.

Roof

Insulation is ½-in. cork board—density 10 to 12 lbs./cu. ft. This is located in the roof panels and not in the ceiling, thus giving the required thermal insulation besides acting as a sound absorbent.

The aluminium alloy troughing section is designed to carry all the necessary roof loads, the outer sheet covering merely providing weather protection and the cork acting solely as insulation. Each of the four units has two roof trusses, which are supported off the external walls and centre partition and provide a means of site jointing as in the floor frame. The design is suited to support ceiling bearers arranged at nodal points.

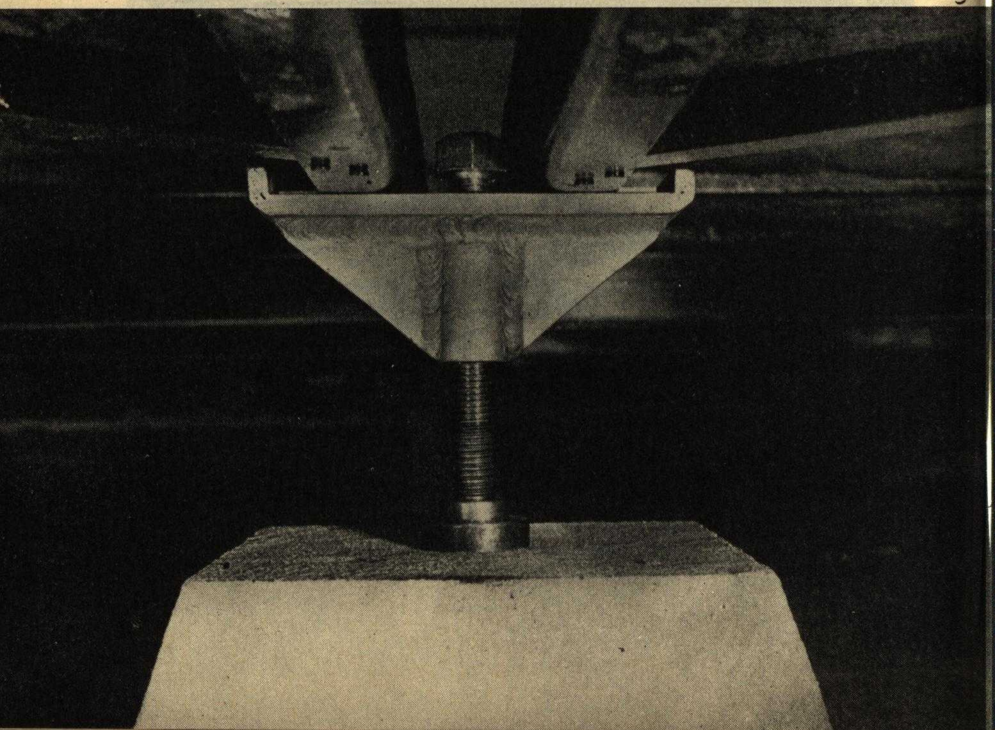
Floor

Insulation is provided by a blanket of felt tacked to the underside of floorboards. Alternatives are glass silk enclosed in waterproof paper, or Stillite in blanket form or other similar materials. A total conductivity of 0·15 is aimed at.

MAINTENANCE

Generally, all exposed structural and weathering aluminium has been painted, the surface being degreased with a chemical cleanser before priming. Provided the correct primer—zinc oxide, zinc chromate or aluminium paint—is used, any type of paint may be employed for the finishing coat. Painted aluminium surfaces do not require repainting at

141. Screw jack for adjusting differences in site level.



such frequent intervals as other common building materials, so that aluminium components combine long life with low maintenance costs.

The A.I.R.O.H. Technical Committee are of the opinion that, if the houses are properly maintained, the life will be as long as that of any built with traditional building materials.

CONCLUSIONS

The A.I.R.O.H. system of building is the only one which interprets the real meaning of "Prefabrication" as opposed to Unit Construction. The outstanding advantages of the system can be summarised as follows:

1. The house is factory built and finished to a much greater extent than any other prefabricated type.
2. Site assembly has been reduced to an almost irreducible minimum.
3. No building trade labour is employed except on roads, sewers, etc.
4. The house is 100% recoverable, since it is mobile and is not therefore tied to any one site.
5. It can be mass produced.
6. It can be built to fulfil any "life" period required.
7. When designed as a "permanent" house it can be altered, added to, or reduced at any time.
8. Any suitable materials can be adapted to its "make-up" as they become available.

ACKNOWLEDGMENTS

Acknowledgments are made to the following:

To the United States Embassy for their help in providing information on the T.V.A. Housing Scheme, who have carried out a project of "sectional" housing on somewhat similar lines in other materials.

To the M.A.P. Production Committee on *The Use of Light Metals in Housing*, on whose report of the 14th September, 1944 the use of light metals was based.

To the various members of the Aircraft Industries Organisation on Housing who gave valuable assistance in the "design" period and to the aircraft workers and technicians, lent by these firms to produce the prototype, who carried out the work with such excellent craftsmanship and keenness.

SECTION VIII

SIX HOUSE DESIGNS

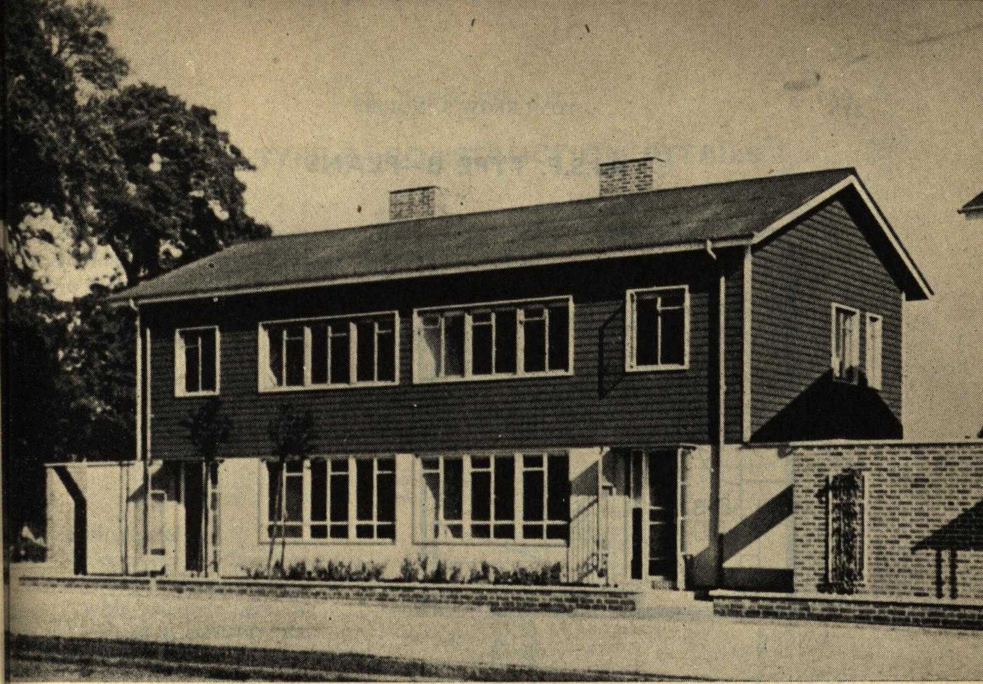
THIS book as a whole is more concerned with the principles of selection of materials and techniques than with the details of any particular house design. By way of contrast, the following section illustrates six type designs which have been worked out in detail and prototypes of which have already been built.

The material, together with the illustrations, on which this section is based was collected by the Housing Centre, 13, Suffolk Street, Pall Mall, S.W.1, and was originally presented in the form of posters for a travelling exhibition. It would have been a difficult job to have included all, or even most, of the designs which have been prepared in the last year or two; even if this were done, the multiplicity of types would tend to confuse rather than to instruct. It is hoped, on the other hand, that the reader will find in the six types here described, each of which is outstanding in its own line, a practical demonstration of the arguments contained in this book.

No one who studies the following pages can fail to be impressed by the new perception in house design which they personify. This perception is born of a temper of questioning, in which traditional methods, however well tried, are only retained if they can justify themselves as being still the best ways of solving the problems of building. At the lowest estimate, this agnostic mood has provoked some uncommonly clear thinking on what standards of performance—heat and sound insulation and weather resistance, for example—should be demanded of a modern house. A systematic approach along these lines involves a revolutionary break with the earlier tradition of accepting without question the rule of the multi-purpose material.

Full credit is due to the Burt Committee, and to the various Committees and full scale projects sponsored by the Ministry of Works; these have already achieved considerable success in formulating agreed standards

It would be wrong to suggest that such current solutions are approaching finality. The ultimate test of experience has still to be survived. At present there appear to be wide and arbitrary variations in design which will probably be narrowed in the process of refinement that we can expect. But such easy criticisms in no sense obscure the fact that house designers are thinking about their problem in a new way and are acting on their new vision.



142.

HOUSE DESIGNS—I. B.I.S.F. TYPE B

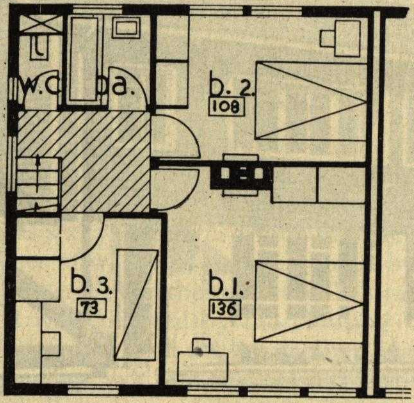
Information based on material supplied by the Housing Centre.

Architect :	Frederick Gibberd.
Engineer :	Donovan H. Lee.
Development :	British Iron and Steel Federation.
Prototypes erected at :	Northolt.

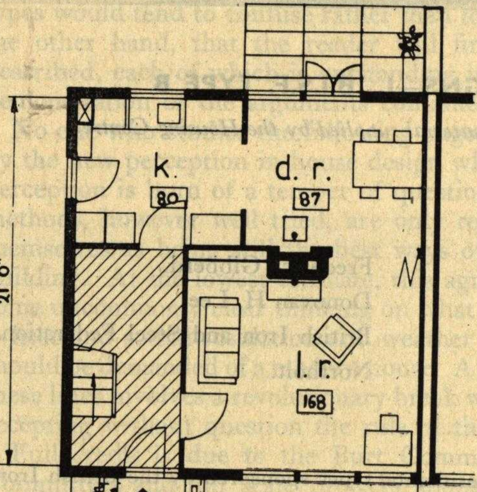
This house is one of three experimental types sponsored by the British Iron and Steel Federation. Particulars of the production models are not yet available. As will be seen, it is not strictly a prefabricated house, consisting as it does of a light steel frame which is erected on the site and to which a variety of external finishes can be attached.

For a further discussion of this principle of construction and for other illustrations of the B.I.S.F. types, the reader is referred to Section V of this book, devoted to Light Steel Frames, which has been contributed by Mr. Donovan H. Lee, M.Inst.C.E., the consulting engineer responsible for the structural development.

B.I.S.F. TYPE B—PLANS



143. FIRST FLOOR



144. GROUND FLOOR

KEY :

b1, b2, b3	bedrooms
ba	bathroom
lr	living-room
dr	dining-room
k	kitchen

Hall and landing hatched.

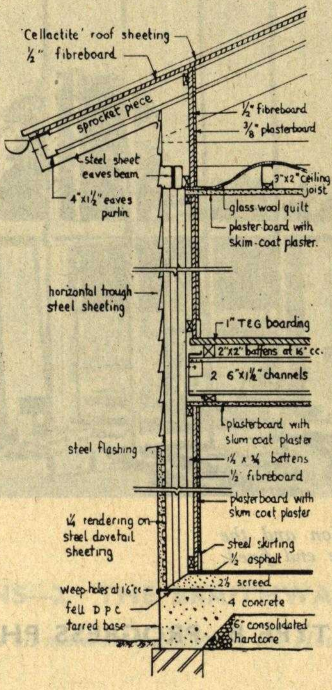
AREAS :

Type B = 860 sq. ft.

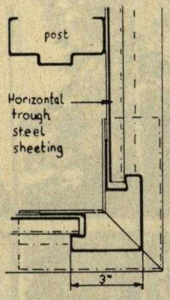
Room areas in sq. ft. as marked on plans.

B.I.S.F. TYPE B—CONSTRUCTION DETAILS

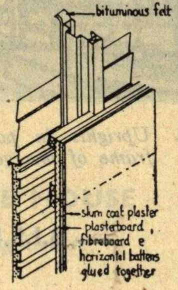
145. *Apart from the care in detailing which characterises this design, it is of particular interest for the widespread use of sheet steel.*



Section



Plan: Corner post



Isometric of external wall

FOUNDATIONS

Concrete footings to external and party walls with concrete ground slab over hardcore and with waterproof membrane over whole surface.

WALLS

Structure. Cold rolled steel sections spot and ridge welded. Posts spaced at 3 ft. 6 in. centres. Assembly takes place on site, all pieces being light enough for two men to lift.

External Facing. Cement rendering on dovetail steel sheet or wire mesh fabric to first floor level; above, horizontal ribbed steel sheeting galvanised and painted.

Inside Lining. Plasterboard panels factory-bonded to fibreboard, finished with a skim coat of plaster.

PARTY WALL

Two leafs of 3-in. foam slag, structurally separate except at outside walls.

FIRST FLOOR

1-in. boarding on battens on steel joists. Ceiling of plasterboard with skim coat of plaster.

GROUND FLOOR

Linoleum fixed by adhesive to cement rendering over waterproofed surface of site concrete slab.

ROOF

Cellactite roof sheeting laid on ½-in. fibreboard. Roof trusses of light gauge steel. Ceiling of plasterboard with skim coat of plaster; glass silk quilt for insulation.

PARTITIONS

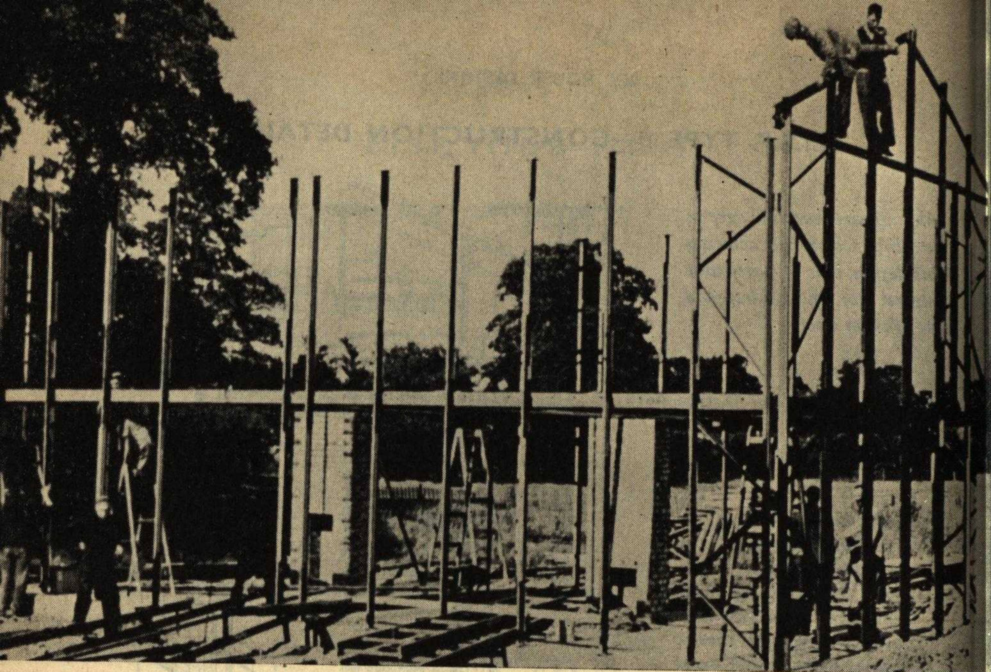
2-in. breeze or foam slag finished with ½-in. plaster.

INSTALLATIONS

Gas, electric, water and main drainage.

SITE MAN-HOURS

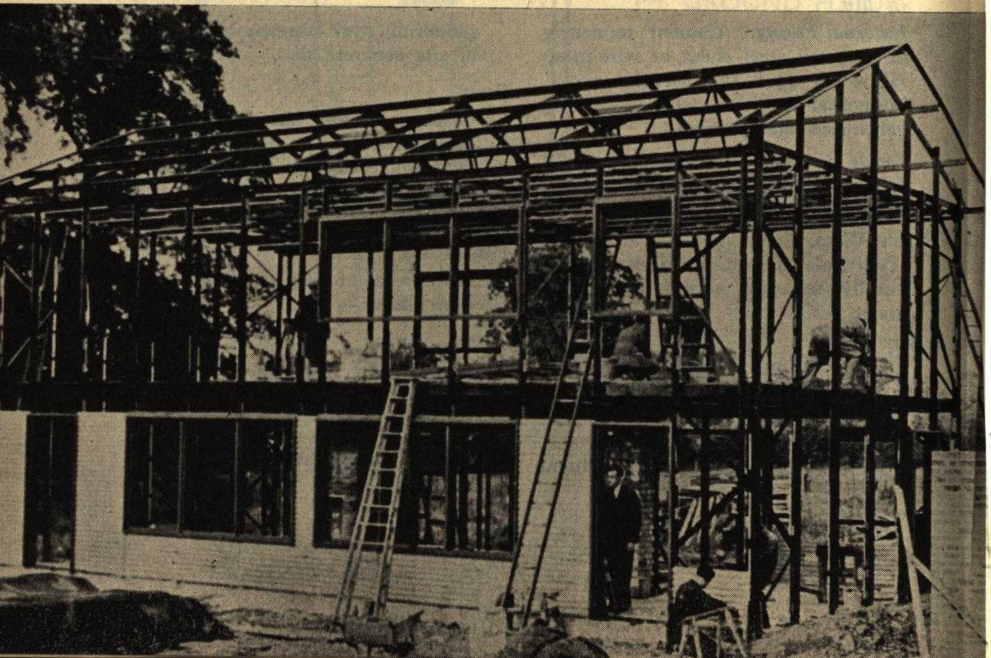
Details not yet available.

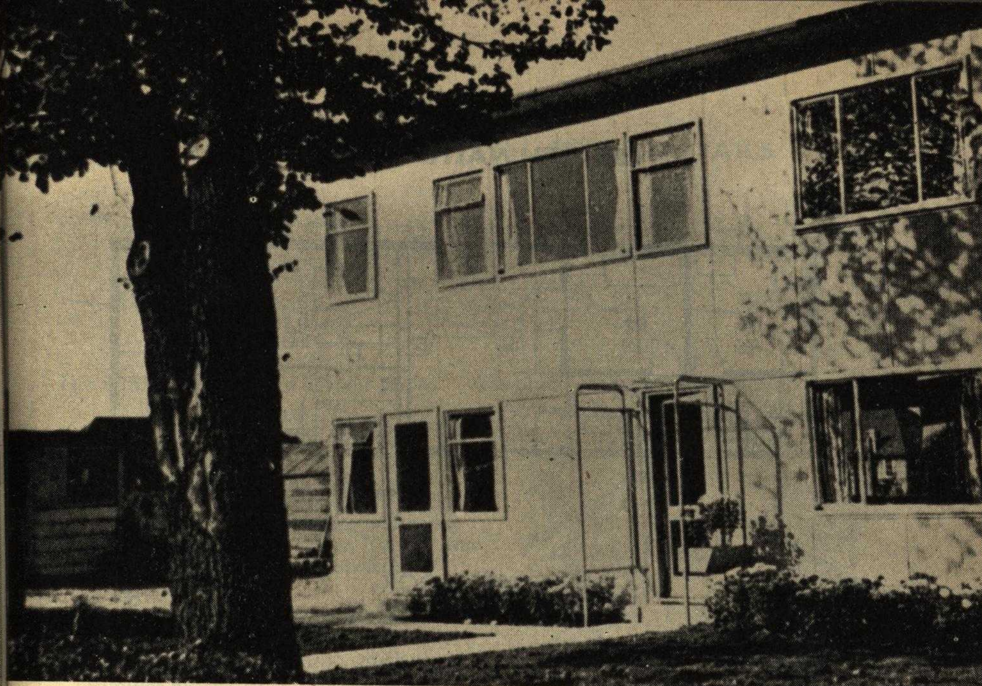


146. *Uprights in position and the frame of one gable end fixed.*

B.I.S.F. TYPE B—PROGRESS PHOTOGRAPHS

147. *The frame complete. Work proceeding on the ground floor walls.*





148

HOUSE DESIGNS—2. THE BRAITHWAITE HOUSE

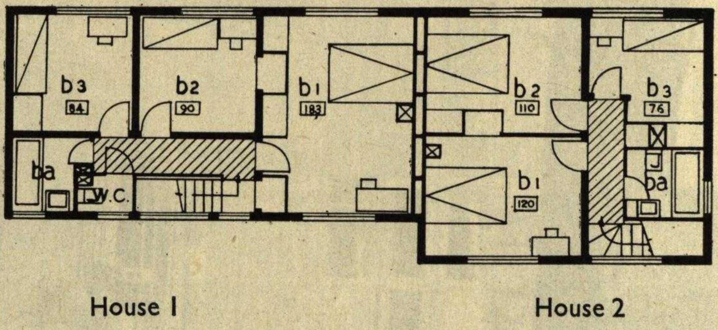
Information based on material supplied by the Housing Centre.

Architect :	F. R. S. Yorke.
Development :	Braithwaite and Co., Ltd.
Prototype erected at :	Hendon.

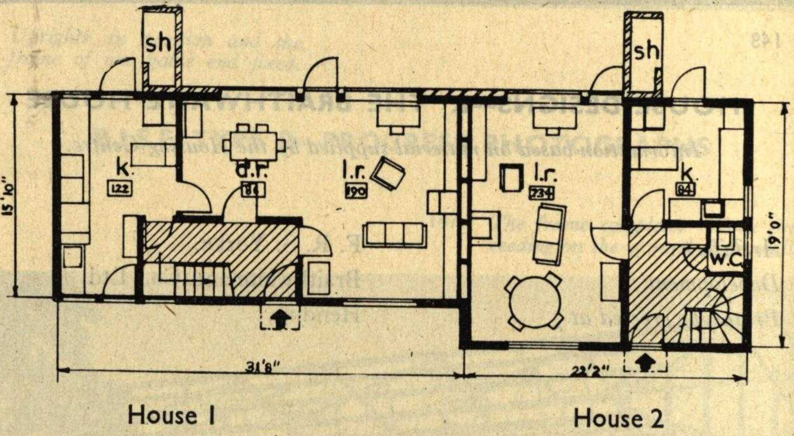
This is one of the examples of unit frame construction. While the frame is prefabricated, the rest of the house, including the cladding, is put together on the site. This combines the advantages of dry assembly and standardisation with considerably greater flexibility than a fully prefabricated system allows.

This flexibility is symbolised in the erection of the pair of houses illustrated here, whose plans are entirely different, even in depth. The same method of construction can be used for three storey flat types.

BRAITHWAITE—PLANS



149. FIRST FLOOR



150. GROUND FLOOR

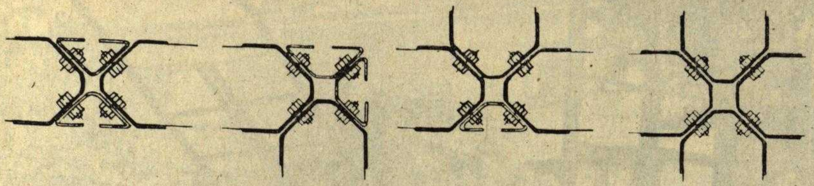
KEY :

b1, b2, b3 . . . . . bedrooms
ba . . . . bathroom
lr . . . . living-room
dr . . . . dining-room
k . . . . kitchen
sh . . . . shed
Hall and landing hatched.

AREAS :

House 1 = 960 sq. ft.
House 2 = 810 sq. ft.
Room areas in sq. ft. as marked on plans.

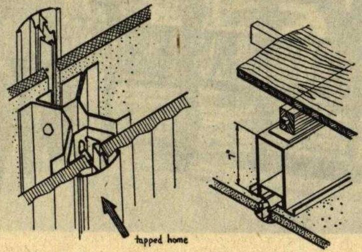
BRAITHWAITE—CONSTRUCTION DETAILS



Two in line. *Two at right angles.* *Two in line and one at right angles.* *Four meet at a point.*

151. Detail plans of four types of Frame joint, illustrating flexibility.

152. Two Isometric views
Left: *Wall spring clip fixing, and cladding materials.*
Right: *Floor joist, floor and ceiling construction.*



FOUNDATIONS
Continuous walls of in situ concrete. Stanchion holes, 9 ins. deep, take the legs of the frames which are grouted in.

WALLS
Structure. Built up of welded frame units formed from cold-rolled or pressed sections of light-gauge steel, one or two stories high and either 3 ft. 1½ in. or 6 ft. 3½ in. wide. Four of these can be seen in the upper progress photograph overleaf.
Outside Facing. Main material in prototypes is ½-in. thick asbestos cement sheeting with small vertical flutes. These sheets, 3 ft. 1½ in. wide and up to one storey in height, require no painting. They are secured to the steel frames by a special clip section, which also weathers the joints. Other materials can be used, including 4½-in. brickwork or precast concrete slabs.
Inside Lining. A variety of forms of sheeting can be used, including Jixonite, cellular plywood, fibreboard, plasterboard and glazed asbestos cement sheeting. The latter is ¼-in. thick and the others are ½-in. thick. Additional thermal insulation, required in the case of all materials except Jixonite, is provided by slag wool, rock wool or aluminium foil.

PARTY WALL
This is made fire-resisting by means of two leaves of 2½-in. thick precast concrete blocks, placed between independent steel frames.

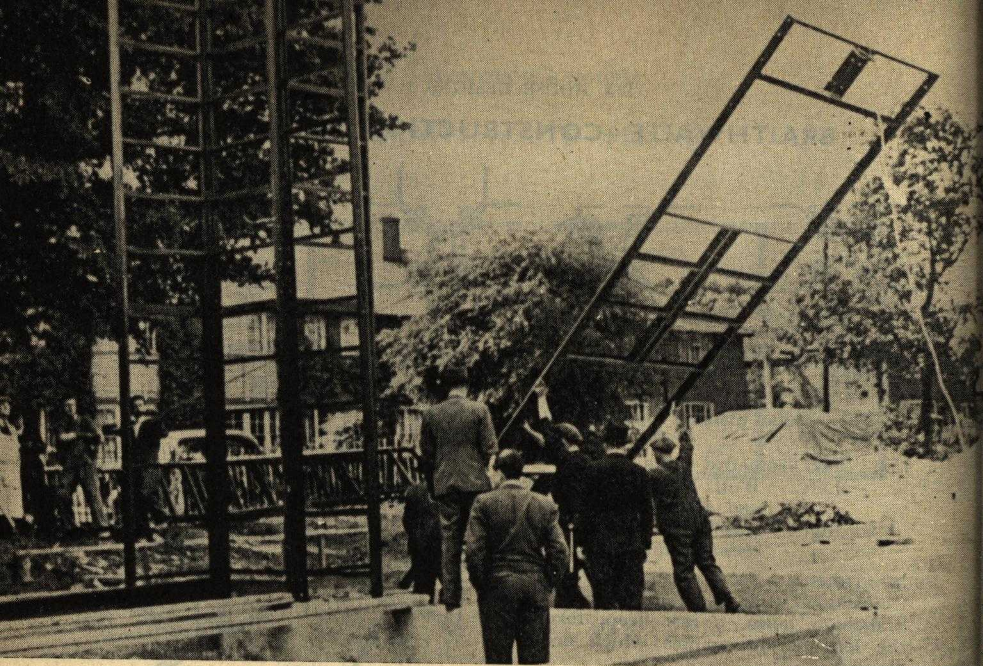
FLOOR AND ROOF STRUCTURE
Cold-rolled light-gauge steel beams of special design, generally 7-in. deep, bolted into the vertical framework. Floors are of the floating type, resting on fibreboard or cork strips. Roof is of lightweight concrete slabs: all other floors of ½-in. blockboard or T. and G. flooring stiffened with deal battens at about 1 ft. intervals. Concrete slabs can be used for kitchens and offices.

PARTITIONS
Steel frames similar to the main structural members are used, and are covered with suitable lining materials.

INSTALLATIONS
Plumbing is largely prefabricated. Electric wiring and piping are housed within the frames and floor units. By convection, heat from the living-room flue is used to warm the air of the bedrooms.

SITE MAN-HOURS
Estimated at approximately 1,000 man-hours for a house of 1,000 cu.ft.

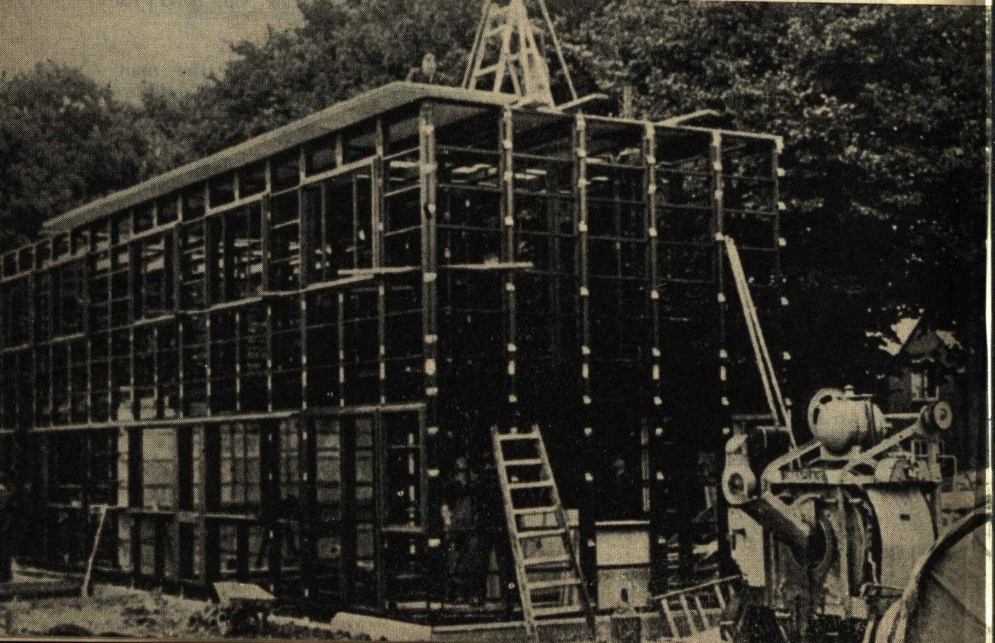
COST
When in full production, it is anticipated that costs will be comparable with those for traditionally built houses.

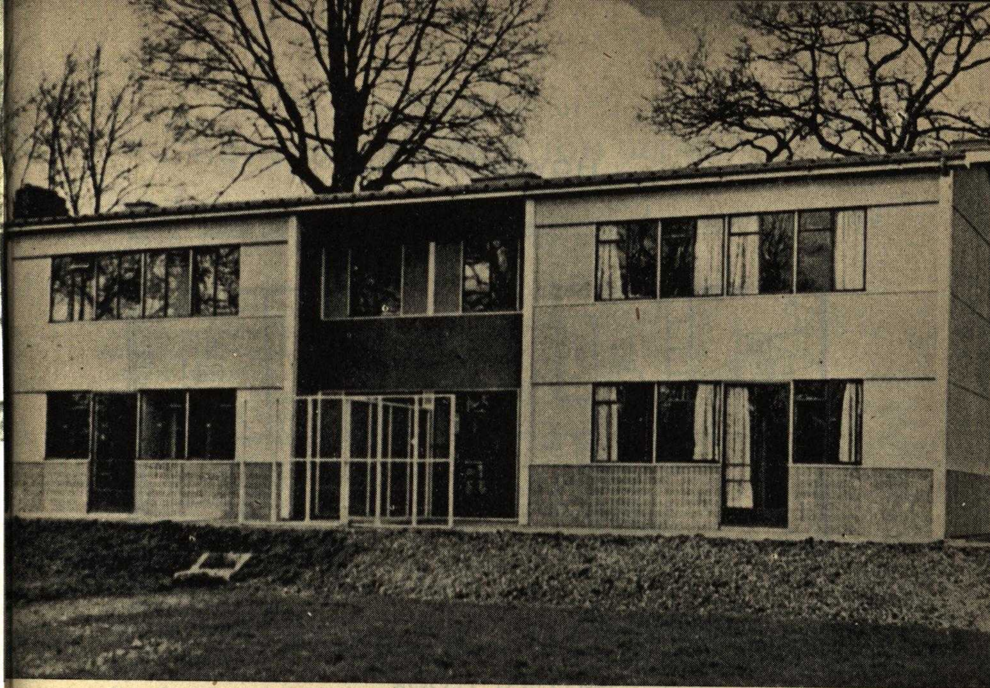


153. *An early section being got into position.*

BRAITHWAITE—PROGRESS PHOTOGRAPHS

154. *The complete frame; fixing of roof and internal panels has begun.*





155.

HOUSE DESIGNS—3. THE HOWARD HOUSE

Information based on material supplied by the Housing Centre.

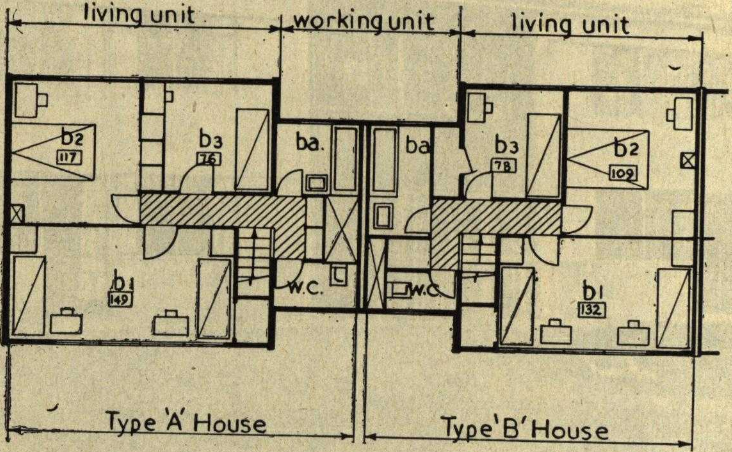
Architect :	Frederick Gibberd.
Development :	John Howard and Co., Ltd.
Prototypes erected at :	Datchet.

This is one of the latest types to be developed, and thus is able to incorporate the main recommendations of the reports made to the Ministry of Health Advisory Committee on House Planning.

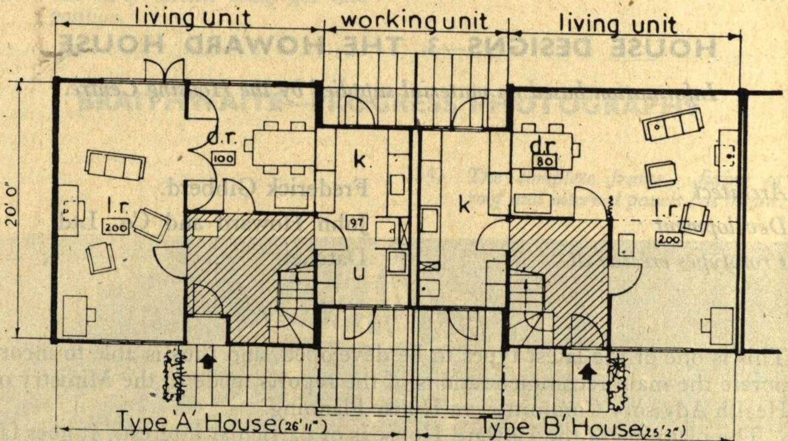
The planning of the Howard House is of particular interest. It goes far to isolate the " quiet " rooms from neighbours' noise ; the double aspect kitchen makes it possible to use these houses in terraces without the need for tunnels or back lanes, and the " works " of the house are all concentrated together.

The structure also is noteworthy, and its wide spacing of posts, with long band beams spanning between them, contrasts with many of the other types illustrated. It will be observed that there is no brickwork, even for flues, and that very little timber is used.

HOWARD—PLANS



156. FIRST FLOOR



157. GROUND FLOOR

KEY:

b1, b2, b3	bedrooms
ba	bathroom
lr	living-room
dr	dining-room
k	kitchen
u	utility room

Hall and landing hatched.

AREAS:

Type A = 993 sq. ft.
Type B = 900 sq. ft.
Room areas in sq. ft. as marked on plans.

HOWARD—CONSTRUCTION DETAILS

Foundation

Concrete bases for the ten main stanchions required for each house.

Main Walls

Structure. Prefabricated horizontal band beams span between inch-wide spaced steel columns, the spaces between the beams being filled with windows or blank non-structural panels set back behind the main wall face, so that the house flashes itself.
External facing. The horizontal units, up to 21 feet long, are of light welded steel sections, delivered faced with asbestos-cement sheeting, or aluminium "weatherboard," finished rough-cast in a choice of colours. Plinth of precast concrete units faced with briquettes or tiles.
Internal lining. Prefabricated internal wall lining units consisting of a light timber frame, cementated wood wool, plasterboard, and aluminium foil.

Party Wall

Two independent leaves joined only at outside walls complete the sound insulation system, which is already largely achieved by planning.

Partitions

Non-loadbearing: double partition units of cementated wood wool with plasterboard face.

Roof

Ribbed asbestos cement roofing sheets on steel purlins on light steel roof truss. The latter are close spaced to receive the prefabricated ceiling linings. Insulation is provided by a slag wool blanket over the ceiling.

First Floor

Prefabricated timber floor units drop on steel floor beams, which are at 3 ft. 6 in. spanning between the band beams and the centre steel span. The underside is sealed with timber and plasterboard units.

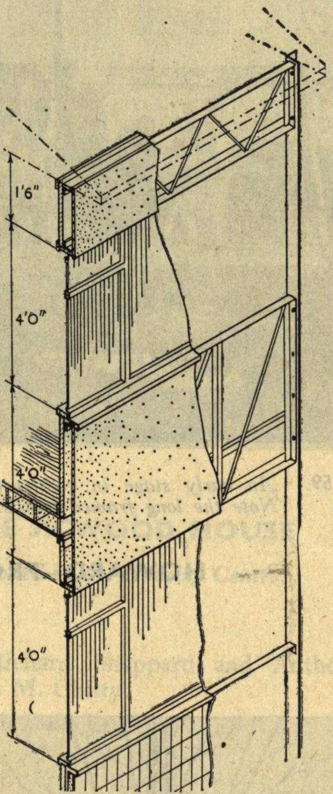
Ground Floor

As for first floor, but without lining on soffit.

Installations

The kitchen is a completely factory-made room. The walls, floors, ceiling, doors, windows and all equipment, such as cupboards, sink etc. are made in the one factory, and the plumbing and hot water services installed. It is then delivered on a lorry to the site and slung into position by a light crane. The bath basin, W.C., etc. are later stood on the "roof" of the kitchen and connected up to the existing service pipes.
The "Octopus" system of prefabricated electrical wiring is installed.

158.
Isometric section showing panel and floor construction.



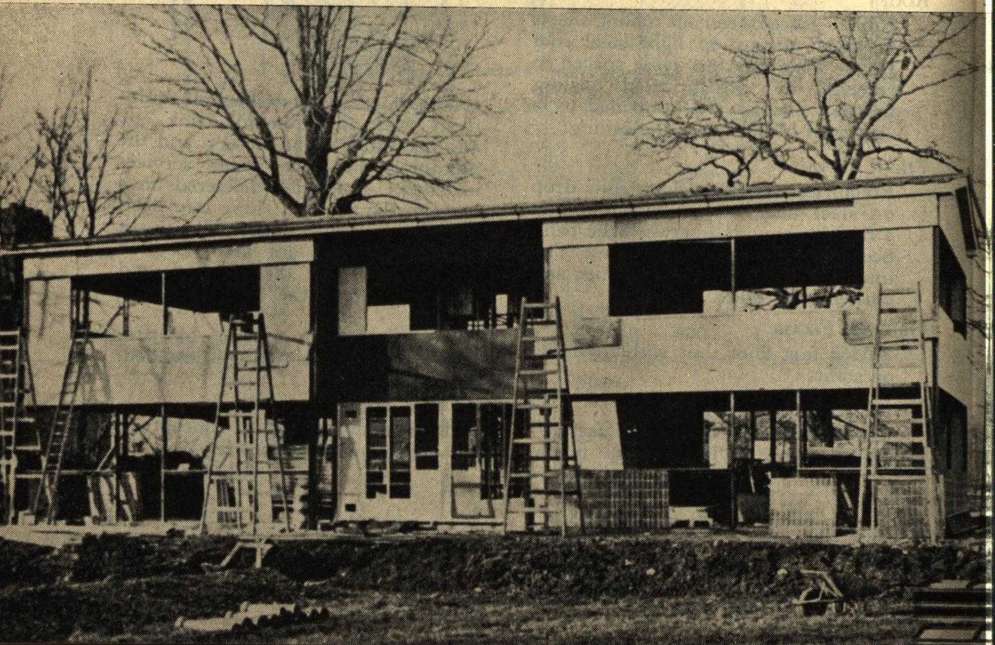
Site Man-hours

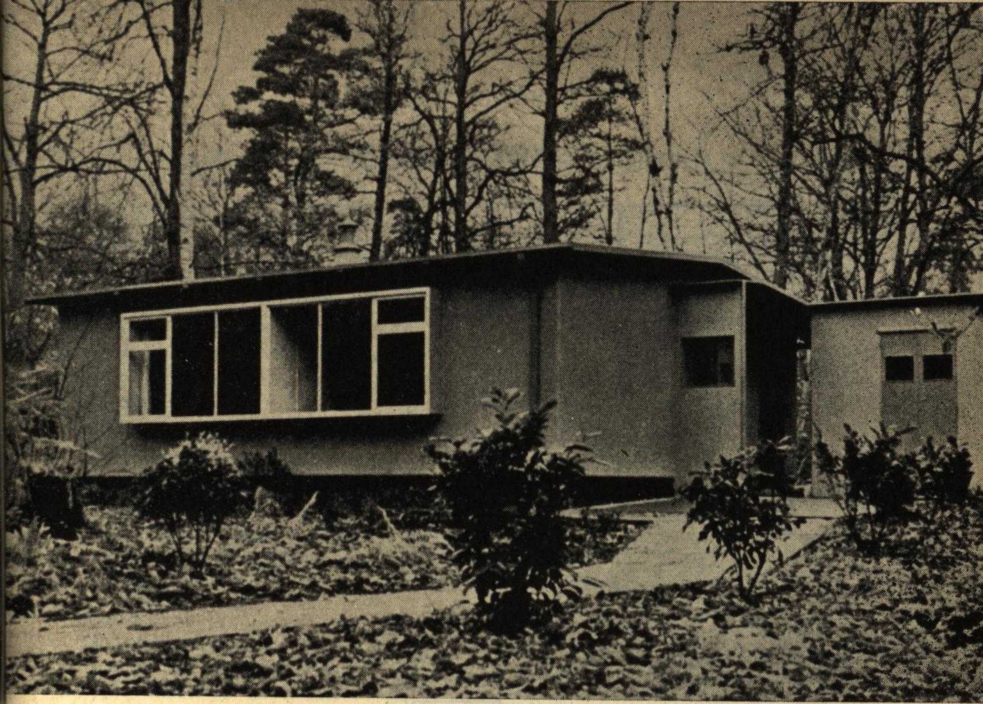
As the house is both factory-made and remarkably simple in conception, site erection is very fast.

159. *An early stage in construction. Note the long framed panels.*

HOWARD—PROGRESS PHOTOGRAPHS

160. *The main shell nearing completion. Slabbed up plinths are awaiting fixing.*





161.

HOUSE DESIGNS—4. THE JICWOOD HOUSE

Information based on material supplied by the Housing Centre.

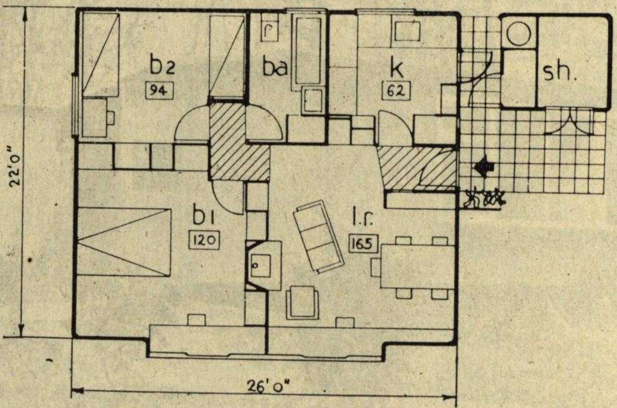
Architects : Richard Sheppard and Anthony M. Chitty.

Development : Jicwood Ltd.

The only emergency type house and also the only single storey type illustrated in this series, the Jicwood timber bungalow is a noteworthy example of stressed skin construction. Although practically entirely of wood, the amount of timber used is said to be only one-third of that used in a similar house of brick construction.

The house provides an interesting comparison with the A.I.R.O.H. house described elsewhere in this book. Both are far more fully prefabricated than any permanent houses illustrated, and are therefore demountable. In the case of the Jicwood house, the loss on reassembly is claimed to be only 5%.

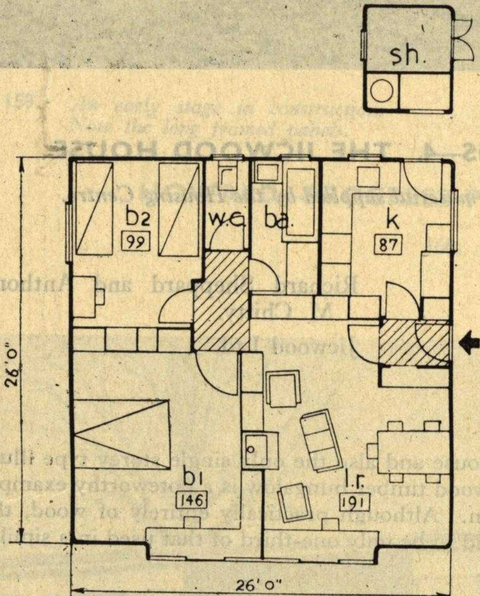
JICWOOD—PLANS



162.

HOUSE 1

This is the type illustrated.



163.

HOUSE 2

KEY:

b1, b2	bedrooms
ba	bathroom
lr	living-room
k	kitchen
sh	shed

Passages hatched.

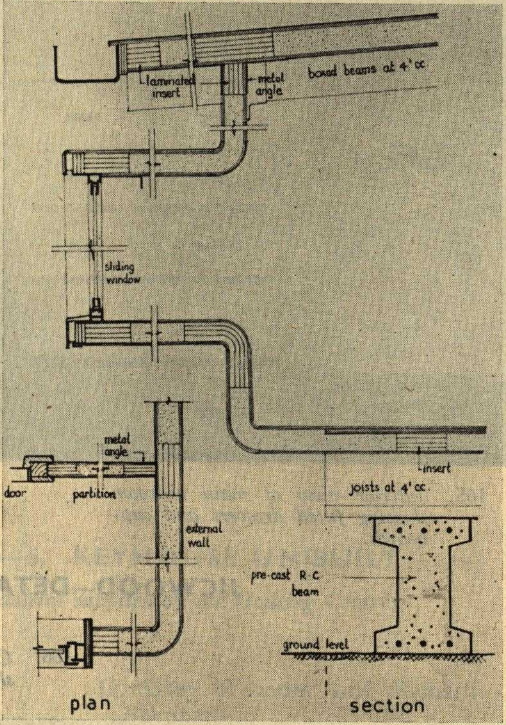
AREAS:

House 1 = 572 sq. ft.
House 2 = 676 sq. ft.
Room areas in sq. ft. as marked on plans.

JICWOOD—CONSTRUCTION DETAILS

164.

This plan and section show very clearly the characteristics of design in laminated wood. Note the curved corners, and the hardwood inserted at points through which nailing will take place.



FOUNDATIONS

Four point support to each of four precast reinforced concrete I-beams.

WALLS

Structure. As the structure is of stressed-skin type, there is no frame independent of the walls.

Main Walls. Plywood as inside and outside facing to insulating and stabilising core of compressed sawdust and paper pulp (or of expanded rubber). The whole wall, bonded together with synthetic resin, is 1⅝-in. thick. External finish can be special veneer, or can be rendered, etc. Internal finish can be special veneer, distemper, wallpaper, etc. Each wall is assembled in factory and brought on site complete.

ROOF

Plywood box beams, 3½ in. wide tapering to suit run of 6° roof (i.e., varying from approximately 6 to 16 ins.) Roof, 1⅝-in. thick, is identical in composition with the walls. It is screwed to the box beams on site.

GROUND FLOOR

Floor joists at 4 ft. centres resting on R.C.I-beams support floor, which is of material similar to that of the walls, but with ¼-in. ply each side to withstand wear.

PARTITIONS

Of similar composition to that of the outside walls, but only 1-in. thick. Not load-bearing, are attached to outside walls by means of metal angles and fit into special fillets on the floor.

INSTALLATIONS

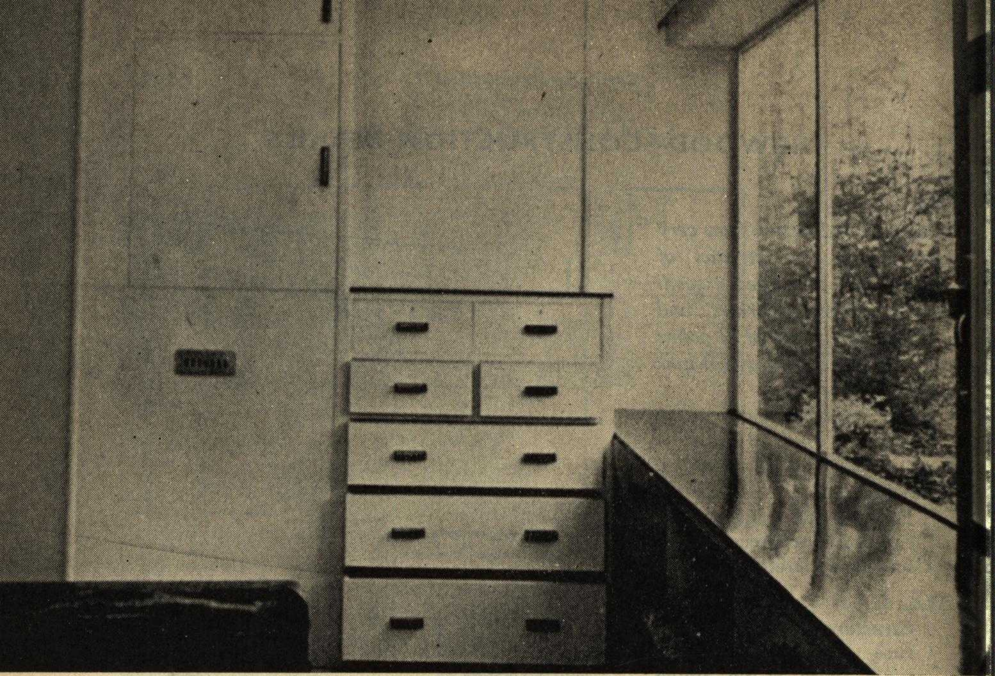
Heating and cooking can be by gas, electricity or solid fuel, to suit local and individual requirements.

SITE MAN-HOURS

200.

COST

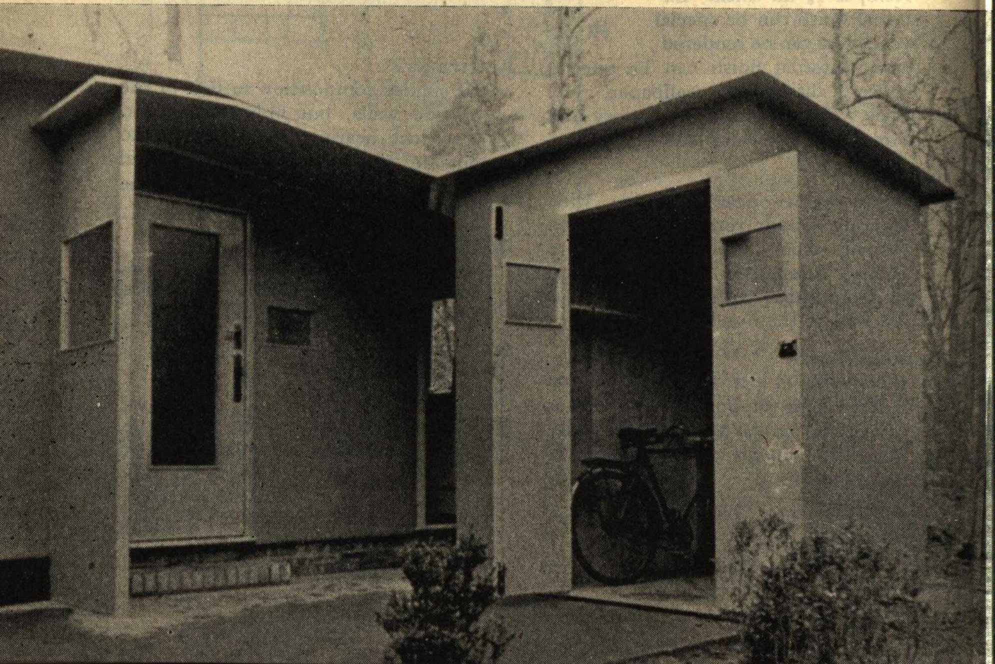
Estimated at £600 for the 600 sq. ft. type, excluding foundation and services.

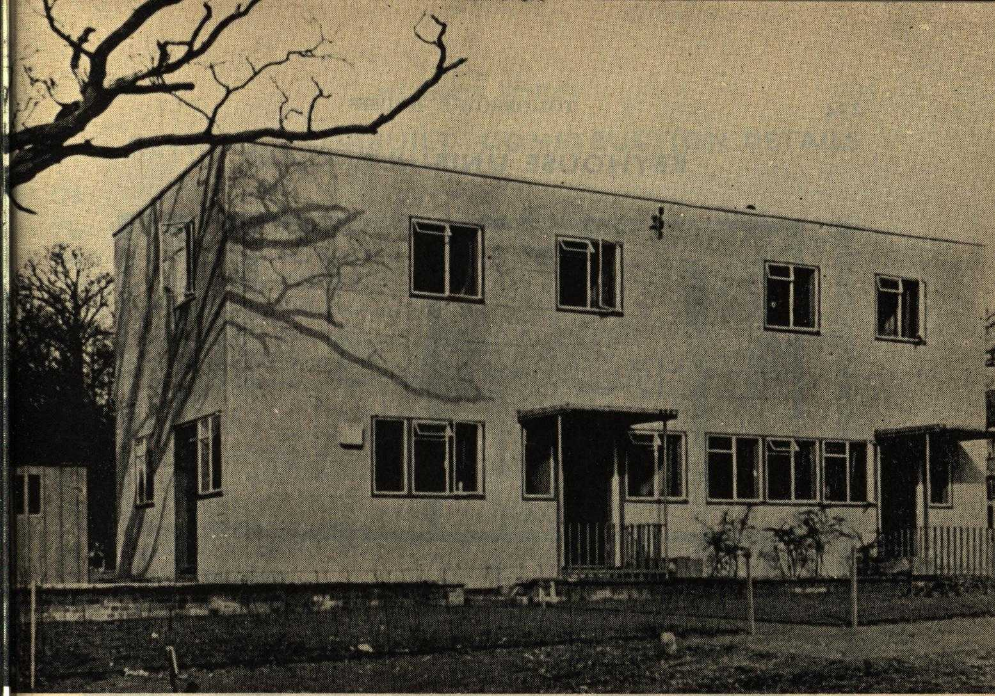


165. *Interior view of main bedroom showing fitted drawers and cupboards.*

JICWOOD—DETAILS

166. *Close-up of front door porch and shed.*





167.

HOUSE DESIGNS—5. KEYHOUSE UNIBUILT

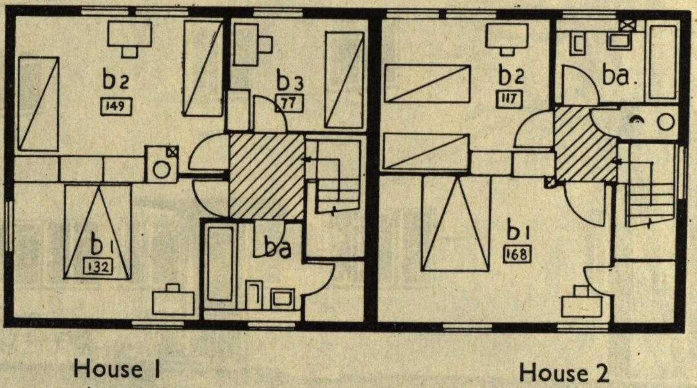
Information based on material supplied by the Housing Centre.

Architects :	G. Grey Wornum and Richard Sheppard.
Development :	Keyhouse Unibuilt, Ltd.
Prototypes erected at :	Canley, Coventry.

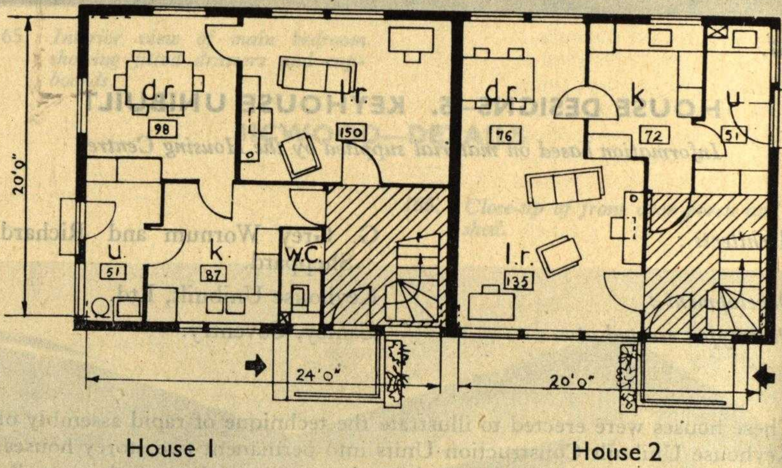
These houses were erected to illustrate the technique of rapid assembly of Keyhouse Unibuilt Construction Units into permanent two storey houses. None of the standardised light steel framing units weigh more than 100 lb. so that the heaviest can be carried by two men. Floor and roof trusses span right across the building, being either 20 ft. or 24 ft.

The Canley prototypes, occupied since October, 1944, should not be considered final or definite, although the tenants appear to have been very satisfied with them. A second pair, incorporating minor revisions, has since been built at Sighthill, Edinburgh.

KEYHOUSE UNIBUILT—PLANS



168. FIRST FLOOR



169. GROUND FLOOR

KEY :

b1, b2, b3	bedrooms
ba	bathroom
lr	living-room
dr	dining-room
k	kitchen
u	utility room

Hall and landing hatched.

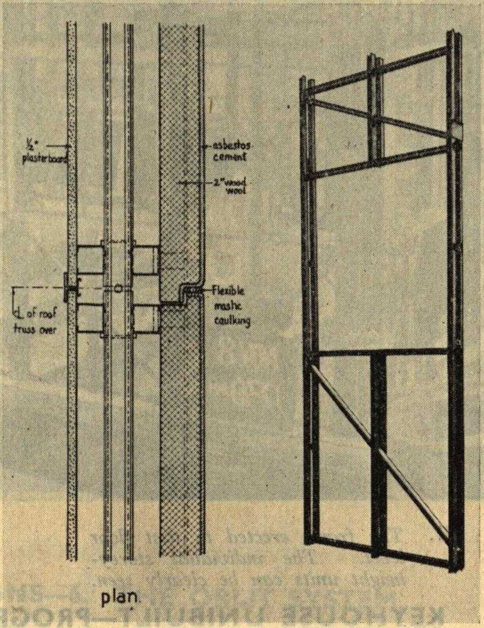
AREAS :

House I = 980 sq. ft.
House 2 = 820 sq. ft.
Room areas in sq. ft. as marked on plans.

KEYHOUSE UNIBUILT—CONSTRUCTION DETAILS

170.

The photograph on the right shows one of the wall frame units from which the house is built up. The plan on the left gives a detail of the materials used internally and externally, and shows the method of jointing.



FOUNDATIONS

Traditional foundations, with brick footings and sleeper walls. Precast concrete cill, complete with anchor bolts is laid ready to receive the light steel framework.

WALLS

Structure. Ridge-welded rolled strip steel sections factory assembled into interchangeable units. Normal units, 4 ft. wide by 10 ft. high, are bolted together on site, designed in varying types suitable for doorways, windows, etc. Frames are joined by square tubular dowels held in position by locating plates, thus eliminating nuts and bolts.

Outside Facing. Asbestos cement pans, 4 ft. wide by 2 ft. high, factory filled with 2-in. thicknesses of wood wool. Joints caulked with waterproof mastic material applied with a pressure gun.

Inside Lining. ½-in. plasterboard.

PARTY WALL

Two 2-in. skins of laminated plasterboard with a core of wood-wool slabs. Complete physical separation of houses except at outside facing and roof.

FLOORS

First floor trusses of factory assembled units, similar to wall frames, span 20 or 24 ft. clear, giving maximum internal flexibility. On these, and on ground floor sleeper walls, rest timber bearers at 2-ft. centres supporting "Escor" aerated concrete slabs 2 ft. by 4 ft. by 2½ in. thick, finished with damp-proof linoleum.

ROOF

Structure and concrete slabs similar to those used for first floor. Roof finished with 3-ply ruberoid.

PARTITIONS

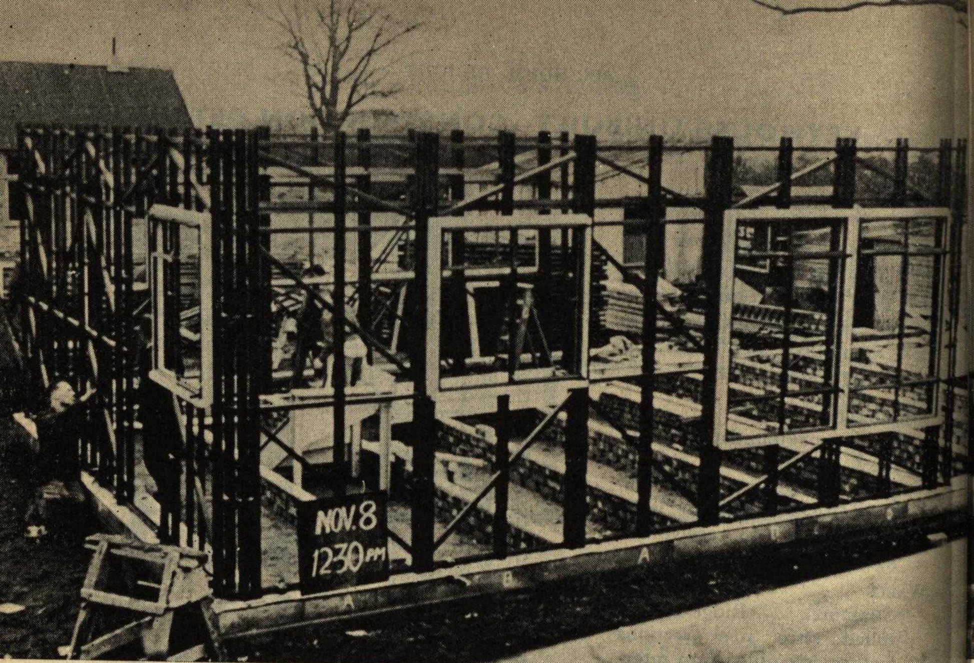
Not load bearing, light steel studding faced with ½-in. plasterboard jointed with flush metal cover strips.

INSTALLATIONS

Space heating by means of "Courtier" stove with back boiler. A 6-in. fluepipe is encased in a ventilated sheet metal duct, thus using warmth for space heating. Supplementary heating by electric radiant panels. Other equipment obtained from such stocks as were available.

COST

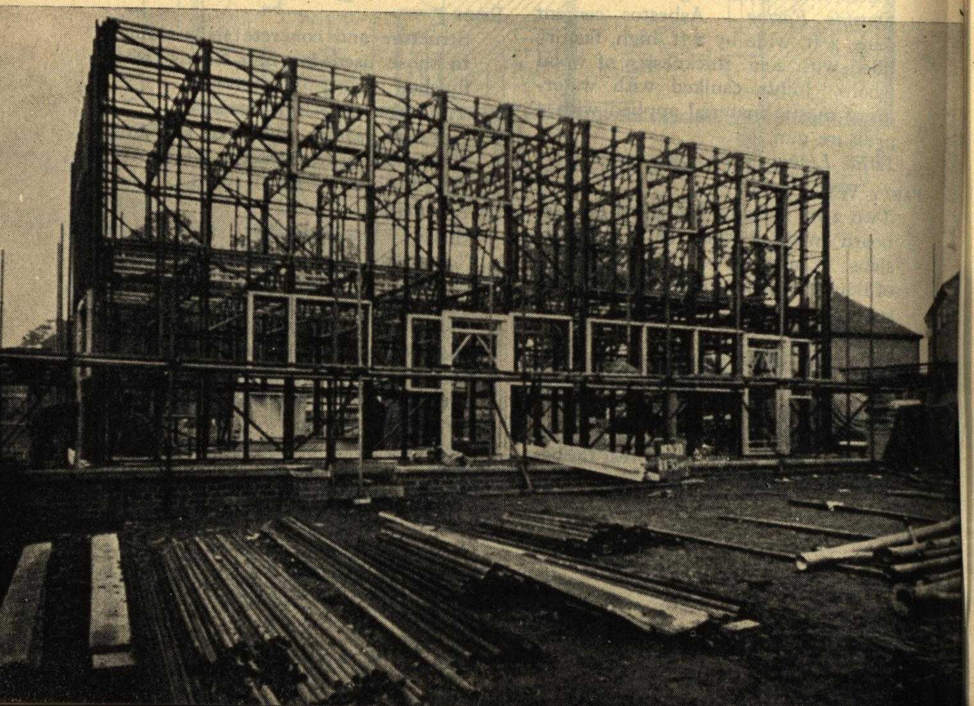
Estimated at £1,000 per house with mass production.

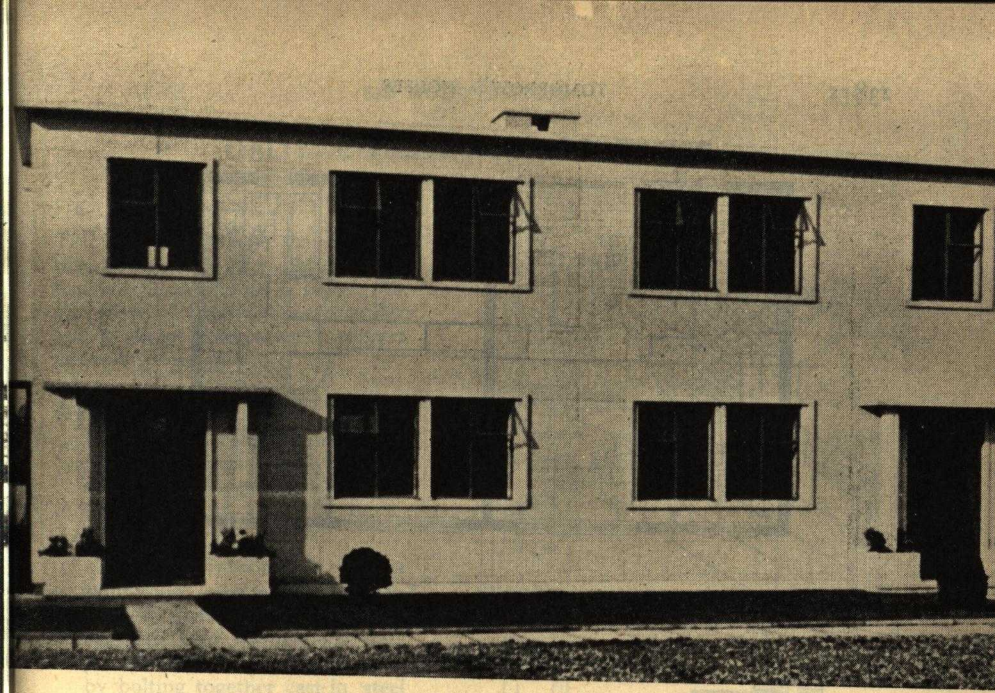


171. *The frame erected to first floor level. The individual storey-height units can be clearly seen.*

KEYHOUSE UNIBUILT—PROGRESS PHOTOGRAPHS

172. *A few working hours later, the frame is complete.*





173.

HOUSE DESIGNS—6. THE ORLIT SYSTEM

Information based on material supplied by the Housing Centre.

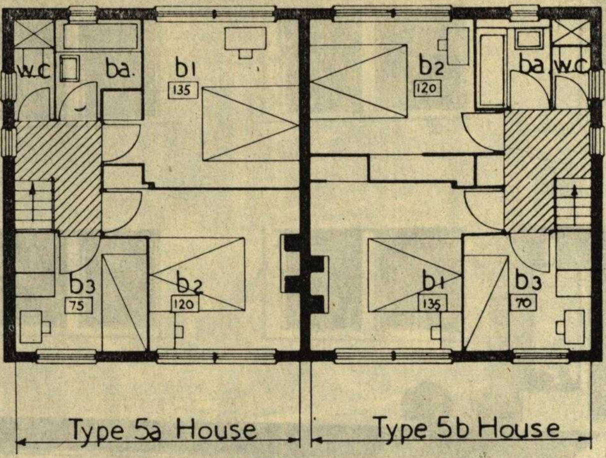
Architect :	E. Katona.
Development :	Orlit, Ltd.
Prototypes erected at :	Colnbrook.

Of the six designs here illustrated, the Orlit system is the only one which makes use of a reinforced concrete frame. The use of this material has led to the adoption of a wide spacing of the structural members.

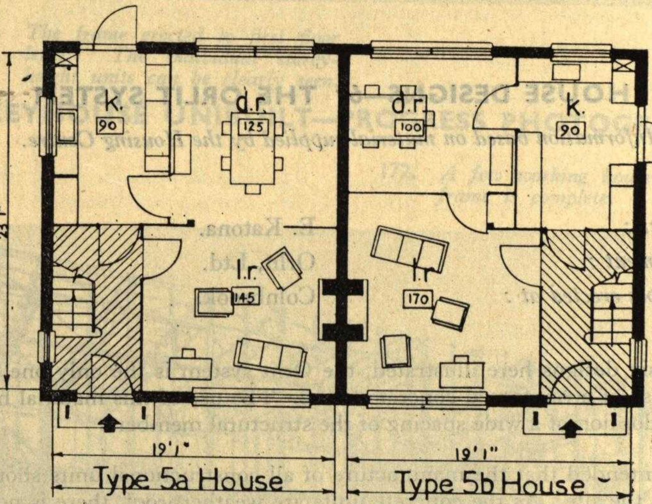
It is intended that the manufacture of all constructional units should be done on the site. As the concrete units are weatherproof, there is no need for storage under cover.

The Orlit system thus relies on site prefabrication. It does not, however, achieve complete dry assembly ; the horizontal frame members are jointed by pouring concrete into a socket formed between them, and the wall panels are jointed and pointed in gauged lime mortar. Against this, it has the advantage that the materials required are readily available throughout the country. It is also claimed that less skill is required for production and erection.

ORLIT—PLANS



174. FIRST FLOOR



175. GROUND FLOOR

KEY:

b1, b2, b3	bedrooms
ba	bathroom
lr	living-room
dr	dining-room
k	kitchen

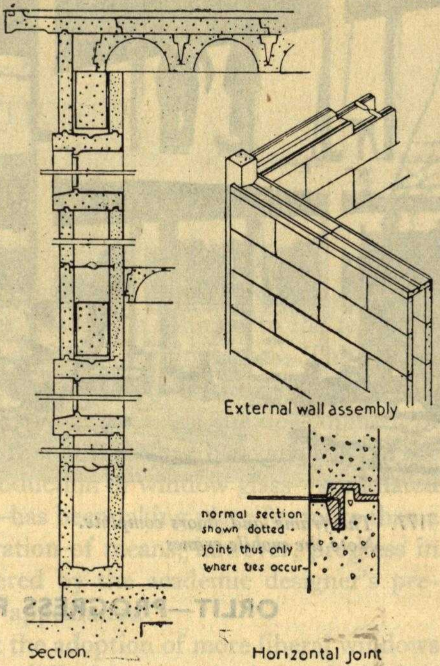
Hall and landing hatched.

AREAS:

Both types = 870 sq. ft.

Room areas in sq. ft. as marked on plans.

ORLIT—CONSTRUCTION DETAILS



176.

This illustration shows the construction, consisting of interlocking precast concrete panels and other units. For this form of construction particular care in design is necessary to prevent moisture penetration.

FOUNDATIONS

In-situ concrete foundations, precast footings exactly spaced and levelled by means of special jig.

WALLS

Structure. Interlocking precast reinforced concrete members. Upright members at 10 or 12 ft. centres. Two connections, one just above each floor, are formed by bolting together cast-in steel plates. Horizontal connections completed by pouring a small amount of concrete into cavities at the overlap.

Outside facing. Orlit concrete slabs with special exposed aggregate finish.

Inside lining. Lightweight concrete (foam slag) slabs plastered, to provide thermal insulation.

PARTY WALL

Orlit slabs forming cavity wall. Leaves physically unconnected. The latest development shows two independent frames to break all structural contact.

FIRST FLOOR AND ROOF

Orlit concrete channels, on which various floor surfaces are used. As an alternative concrete joists and prefabricated timber panel flooring. Ceilings of plasterboard fixed to wood battens inserted between channels.

GROUND FLOOR

Concrete slab or suspended floor similar to 1st floor construction.

PARTITIONS

Tongued and grooved lightweight concrete slabs for semi-dry assembly and subsequent plastering. Alternatively any prefabricated partitions may be employed.

INSTALLATIONS

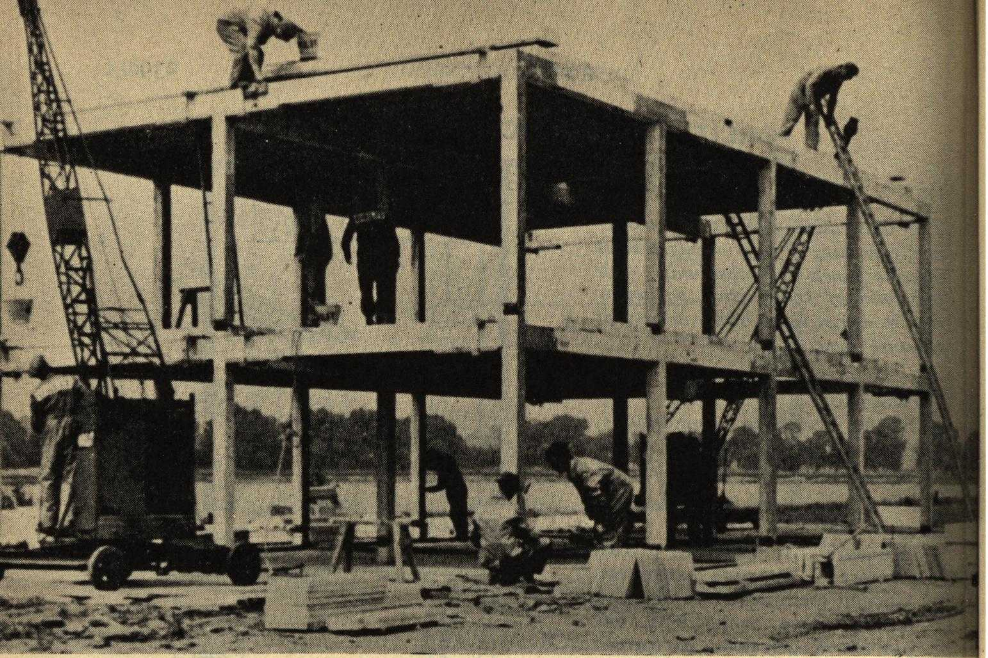
All sanitary fitments are grouped centrally near to plumbing ducts provided with access panels for maintenance and inspection. Electric conduits in pre-cut lengths laid in wall and floor cavities, or behind hollow skirtings.

SITE MAN-HOURS

All units are designed for easy handling and the tie-wedges fix positions of slabs and speed up erection. There is no loss of time from drying out of materials. Frame assembly 30 man-hours, complete structure 230 man-hours, completed house 800–900 man-hours.

COST

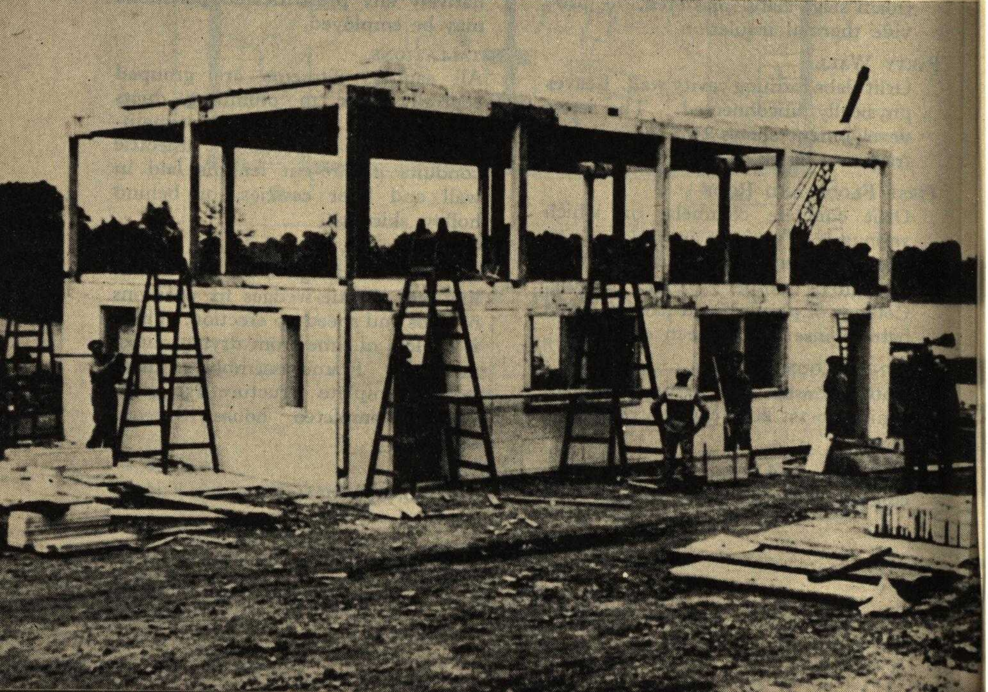
£880 for 880 sq. ft. type.



177. *The frame and floors complete. Note the mobile cranes.*

ORLIT—PROGRESS PHOTOGRAPHS

178. *Walls erected up to first floor level.*



SECTION IX

NATURAL LIGHTING

It is astonishing that we have accepted inadequate standards of indoor lighting for so long after reaching a solution to the technical problems which, in the past, have limited window areas. The history of fenestration is bound up with the history of the development of methods of spanning over large openings and of the development of good cheap window glass. The first of these had been achieved in the middle ages, while the mass production of window glass—stimulated by the removal of glass duties—has been taking place for more than a century. In spite of this liberation of means, however, progress in natural lighting has been fettered by the academic designer's pre-occupation with orthodoxy in appearance.

It must not be forgotten that the adoption of more liberal windows carries with it certain attendant difficulties, not the least of which is the need to take more trouble over heat and sound insulation. It should also not be suggested that every room in every house need automatically have one wall mainly of glass. What is necessary is that high minimum standards of natural lighting should be adopted for all new housing and that there should be no unnatural barrier to an extension in the use of glass.

As the author of this Paper describes, there is at last a provisional Code of Practice on daylight, which has some prospect of being applied. He goes on to show that one of the most material factors in providing good standards is the height and layout of the buildings—whether houses or blocks of flats—and that adequate daylighting may in some cases be the limiting factor to the density of development.

NATURAL LIGHTING

By LUCIFER

ONE of the most basic requirements in our buildings and towns is adequate natural lighting. Fortunately it is one of the most easily provided, when the governing principles are known and applied. Yet many persons in this country live and work in bad or only fair lighting conditions, and many are not yet convinced that natural daylighting is sufficiently important to bother about. Adequate daylighting makes rooms efficient for working, minimizes eyestrain, makes rooms more pleasant, and leads to more hygienic living conditions. Planning for good daylight may result in reduced consumption of electricity, and may indirectly affect natural ventilation, as well as sunlight penetration. The nature of the daylighting problem makes it a complicated subject, as the important factors determining daylight conditions are extremely variable, to say nothing of the various ways which natural daylighting is needed in buildings. These facts help to explain the absence in the past of good workable lighting standards. The task of fixing lighting standards to insure good internal conditions has been facilitated by certain technical advances, which provide the means for the measurement of light, both by calculation and by the use of portable instruments, and make possible the assessment in scientific terms of other related factors.

After a lighting standard has been fixed, the provision of adequate daylighting is first of all a problem of town planning, then a problem of proper siting, and lastly a question of suitable architecture, in the design of windows, room sizes, finish and decoration. In the past century the first two of the above problems were usually ignored and the third problem was reduced to a question of " style " ; windows were shaped to suit the effect desired on elevation. Many of the more progressive architects were just as guilty in this respect as the designers of " tudor " buildings.

Since the beginning of the war, a great deal of investigation into the various aspects of natural daylighting has been carried out on a scientific basis, and this may be said to be summarized in the Lighting Committee's report on the Lighting of Buildings and in the provisional British Standard Code of Practice on Daylight. The purpose of this chapter is to set out the principles involved, so far as they concern housing, to discuss their implications on housing layouts and neighbourhood planning, and to show how the Code of Practice may be useful to housing authorities and other persons concerned with housing.

DAYLIGHT MEASUREMENT AND THE DAYLIGHT STANDARD

Daylight has both qualitative and quantitative properties. If we measure the intensity of light in a room at any point with a photo-electric cell or with any other similar instrument, we can express the degree of intensity in units of foot-candles. But the human eye is not satisfied merely by the provision of a certain degree of intensity ; the eye is also very sensitive to a contrast between a high and a low intensity. For many years now it has been known that the essential requirement in lighting rooms, whether in factories, schools or houses, is to ensure a reasonable relation between the intensity of illumination out of doors and that indoors. The unit of measurement in laying down a lighting standard is therefore called the Daylight Factor, which is the daylight which reaches a point indoors expressed as a percentage of the total light available outdoors over an unobstructed hemisphere. It will be apparent that the daylight factor at a point in a room is affected by the size and position of the window, and that a fall in the daylight factor, or a reduction in the amount of light, will result as the measuring point in the room is moved away from the window. Thus it is necessary to specify the depth of penetration required for a daylight factor figure, in order to have a comprehensive daylight standard.

In practice different types of buildings, such as schools, offices, or houses, require different daylight standards, but the requirements are all based on the same principles. The differences are partly due to the varying degrees of fine eye-work, reading or the like and partly due to the different physical use of rooms of different types. The daylight factor figure in the first case and the depth of penetration in the second case are varied to suit the use-type. The Codes of Practice Committee in their Code on daylight have laid down provisional standards on this basis. They make a distinction between kitchens, living rooms and bedrooms in setting their standards. The Code also suggests the minimum floor area which should have daylight up to the specified standard.

The value of setting a daylight standard lies in the fact that, once it is accepted as being workable, it enables rooms to be planned with a remarkably accurate forecast of the sort of lighting which will result. The methods of prediction will not be discussed here since they are dealt with elsewhere. The method of using simplified tables devised by the Codes of Practice Committee, and published in their provisional Code on Daylight, will be found the most straightforward and generally the most acceptable to the non-technical person. The method of using the tables is explained in the Code of Practice.

There are several other factors which affect the quality and quantity of daylight in rooms. To obtain any particular daylight factor value, at

a given depth of penetration, the plan and section must be drawn, with the window. The reference points for calculation of the daylight factor are usually taken on a horizontal plane, 2 ft. 9 in. above the floor. If a line is drawn from a reference point on this plane, on a section through the room to the skyline outside the building—whether natural horizon or roofline of another building—we will have determined the angle of obstruction. If a second line is drawn from the same reference point to the window head, then the angle formed by this line and the line of the angle of obstruction represents the limits, on section, of the sky area to be seen from the reference point taken. Since it is the total sky area visible on the reference plane which in practice determines the daylight factor, it is clear that it is necessary to know the height and position of obstructions to the view of the sky. Such obstructions, usually buildings or high walls, have very little value in reflecting light into the windows opposite, even when white glazed bricks are used ; thus it is customary to ignore all areas visible from the crucial reference points in the room except the unobstructed sky areas. But variations in lintol heights or increases in the required depth of penetration cause different sky areas to be visible between the angle of obstruction and the angle formed between the point of reference and the lintol. Thus it will be seen that to limit the angle of obstruction does not in itself safeguard a reasonable standard of daylighting. The presence of glazing bars and window jambs may have the effect of further reducing the area of the sky visible. The Provisional Code of Practice puts forth a simple method for taking obstructions into account.

In the design of houses or flats, there are certain features which may impede the provision of good natural daylighting. Balconies over windows, bay-windows and dormer windows are examples, since they all reduce the depth to which light penetrates into rooms. This is due to the fact that the sky area visible in the room is reduced by the obstruction at the head of the window. Such features are not necessarily undesirable, but the greater effective depth of the room must be taken into account.

It is also evident that the relation between room depth and window size and proportion is a vital factor in determining what proportion of the room will in daytime be lighted reasonably by natural daylight. Increases in general room sizes which may follow improved housing standards, should be accompanied by corresponding increases in window sizes.

Two other considerations, not directly concerned with daylight planning technique, affect daylighting in rooms. The first is the transmission of window glass. Loss of intensity of daylight due to its passing through the window glass does in fact occur, but in practice this loss is either accounted for by a safety factor included in the daylight standard, or is taken into account during the calculation of the daylight.

The second factor affecting daylighting in rooms is the hanging of curtains over or around the windows. Often the use of curtains over windows to secure privacy is more an indication of bad siting than of anything else. Where ordinary curtains are likely to be provided for occasional use, pelmets may reduce the depth of penetration of the light by lowering the effective height of the window head ; this can only be overcome by incorporating a pelmet, or a similar device, in the original design for the window in such a way that it does not obstruct the daylight. If this is not possible, allowance for the loss can be made in calculating the lighting conditions. The colour of surfaces and their texture has a greater effect on the success of artificial lighting than on natural lighting. It is not customary to take internal finishes into account when designing for good daylight.

The minimum daylight standards which have been referred to should not be thought of as anything but minimum standards. They do not imply that ideal daylighting will result. It is always preferable to work out the requirements in more detail in each individual case. Subtleties in the location of different daylight factor areas are possible, and the examination of a proposed plan from the point of view of contrasts is desirable. The controlled use of natural lighting to enhance the architectural merits of a scheme is perfectly legitimate, provided the designer has the skill to carry it out. Daylight Factor Protractors, developed by the Building Research Station, enable such more detailed studies, to be made with greater refinement than is possible with rule-of-thumb methods.

A survey on the lighting of flats and dwellings, carried out by the Wartime Social Survey, a section of the Ministry of Information, provided some interesting facts on the subject ; these range from the kind of lighting conditions to be found in ordinary homes to the opinions of the occupants on how satisfactory these conditions are in practice. The daylight factor values and the depths of penetration were the subject of part of the investigation. Thus it was possible to summarize what standards of daylight and what penetrations were found to be desirable and what were the minimum tolerable conditions for each type of room. This formed a valuable check on the task of laying down daylight standards for general use in housing.

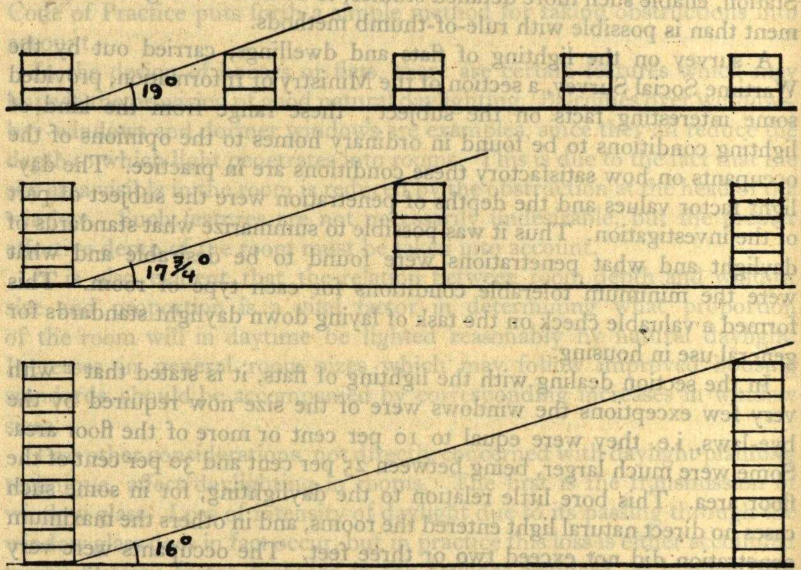
In the section dealing with the lighting of flats, it is stated that " with very few exceptions the windows were of the size now required by the bye-laws, i.e. they were equal to 10 per cent or more of the floor area. Some were much larger, being between 25 per cent and 30 per cent of the floor area. This bore little relation to the daylighting, for in some such cases no direct natural light entered the rooms, and in others the maximum penetration did not exceed two or three feet. The occupants were very conscious of the deficiency, and found their consequent expenditure on artificial light a very considerable addition to the cost of living."

The window has, of course, other functions in addition to daylighting—it must admit air, and, depending upon aspect and situation, may also admit sunlight and provide a view. These questions deserve separate consideration, but it should not be necessary to compromise the lighting conditions.

THE IMPLICATIONS OF THE DAYLIGHT STANDARD

When a lighting standard has been accepted, the method of obtaining lighting up to that standard can only be determined after considering both the internal conditions, as earlier discussed, and the external conditions.

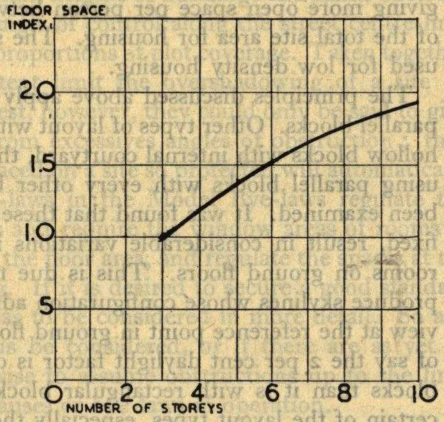
Consideration of external conditions raises problems which do not seem as yet to be fully appreciated. The spacing between buildings is a factor of prime importance, since the angle of obstruction of the view of the sky, as mentioned before, is determined by the height and spacing of the obstruction. This in turn implies that there is a maximum density of development both on small sites and on large housing estates. A maximum density may be expressed either in terms of houses per acre, persons per acre or floor area per acre. But, whichever unit of measurement is used, there is a maximum figure, within the limits of which it would be possible to secure lighting conditions up to the Daylight Standard, assuming proper design of the individual buildings.



179. Diagram showing decrease in the angle of obstruction with increase in the number of storeys at constant housing density.

Thus if it were required to develop a large site for housing at a density of say 130 persons to the acre, and part of the site were developed very sparsely, it would follow that it might be necessary to develop the rest of the site at a higher density than could be permitted in view of the Daylight Standard proposed. As will be shown later, it is possible to overcome this difficulty to some extent by means of variations in the number of storeys of the buildings; but in any case it is advisable that the whole development should be considered as a whole.

Figure 179 shows three-storey buildings, placed parallel to each other, with the consequent angle of obstruction. If every other block is removed and placed on top of the remaining three-storey blocks, the buildings would be six storeys high and the angle of obstruction would be reduced as shown. The same principle would give twelve-storey blocks an even lower angle of obstruction. Thus it is shown that for a fixed density, the angle of obstruction diminishes as the number of storeys increases. This effect, in housing, is most pronounced when the storeys number between three and about twenty. There are two ways of viewing this relationship. One is that an increase in the number of storeys, at a fixed housing density, results in improved lighting conditions and in greater depths of penetration. The other is that, working to a fixed standard of daylight illumination, it is possible to increase the density by increasing the number of storeys. On this point rests one of the technical justifications for the use of tall buildings as against two-storey development. In two-storey development an angle of obstruction to ensure minimum lighting conditions is not usually the factor limiting spacing between buildings—the maximum density being determined by the sizes of gardens, the spacing required for ease of access and for privacy. In the use of taller buildings or flats, increases in the site density along the lines suggested as possible in the graph, Fig. 180, are only justifiable if the proportion of space not covered by buildings to the whole site area is correspondingly increased; then increases in the density will not necessarily mean any deterioration in the lighting conditions.



180. Maximum Housing Densities. 30-ft. wide blocks, based on Minimum Daylight Standards.

If we know the type of house or flat plan proposed, we can translate the maximum possible density into terms of persons per acre. The relationship described can thus be interpreted as meaning that increases in the number of storeys, with a fixed population density, result in an increase of open or unbuilt-upon space per person. Therefore, in the design of housing developments and especially where flats are contemplated, the population density, the heights of buildings and the amount of open space around the buildings per person must be considered concurrently. Where, for example, a housing development at a net residential density of say 120 persons per acre is proposed, it would be possible to place 5 storey buildings on the site with angles of obstructions to suit the minimum lighting requirements. With such a high density figure this development might cover too great a part of the site to allow enough land for other uses such as play areas or shops. Allowing the same angles of obstruction as before, an eight- or ten-storey development would secure the twofold advantage of giving more open space per person between buildings and of using less of the total site area for housing. The space saved could, if desired, be used for low density housing.

The principles discussed above apply in particular to development in parallel blocks. Other types of layout with T or L shaped units, as well as hollow blocks with internal courtyard, the cruciform plan and the system using parallel blocks with every other block turned through 90°, have been examined. It was found that these types of layout, when density is fixed, result in considerable variations in lighting conditions in typical rooms on ground floors. This is due to the fact that the layout types produce skylines whose configuration admits differing areas of the sky to view at the reference point in ground floor rooms. Thus the penetration of say the 2 per cent daylight factor is deeper in layouts with cruciform blocks than it is with rectangular blocks parallel to each other. With certain of the layout types, especially the type with every other building in a parallel arrangement turned through 90°, it would be possible to allow a higher density than with parallel buildings, maintaining the same daylight standard. The maximum density for housing so far as the requirements of lighting are concerned can be defined as shown in Fig. 180, in terms of the Floor Space Index, which is equal to $\frac{\text{total floor area}}{\text{total site area}}$. This graph would give the approximate values of the Floor Space Index for a 1 per cent daylight factor for a depth of penetration of 10 feet. If we allow 200 sq. ft. per person of floor area, then the maximum population density at 10 storeys would be of the order of 300–360 persons to the acre. It would of course be impossible to develop a whole neighbourhood at so high a figure since there are other space requirements and other planning considerations to be taken into account. Desirable net residential densities are set out in Appendix A of the *Housing Manual*, 1944;

these density figures range from 30 persons to 120 persons per acre as averages for whole housing areas in neighbourhood units. Provided an average of that order were maintained, there is no reason why parts of the housing area should not be developed more intensely to obtain the increased open space per person which should result. But from other points of view the density may be limited. The need for particular orientations and for further limitations of the angles of obstruction to provide a reasonable amount of sunlight, particularly for the winter sun, may considerably reduce the maximum density. Suitable disposition of the buildings for obtaining views and for ensuring safety from traffic on the roads are other factors ultimately affecting the density.

Legislation affecting daylighting, directly and indirectly, includes that dealing with heights of buildings, site coverage and window areas. A clause in the Model Clauses under the Town and Country Planning Act, 1932, regulates the maximum heights of buildings and limits obstructions by prescribing a plane angle of control along the street centre-line. A further clause regulates the proportions of plot coverage. Taken together these clauses do to some extent limit the overshadowing of a site by neighbouring buildings. At best, however, they could only be said to give a poor degree of protection from excessives angles of obstruction ; they do not imply that buildings placed on a site so protected will automatically have good daylighting. Bye-laws in the Model Bye-laws regulate the sizes of courts and light-wells and require the window areas of rooms to be not less than 10 per cent of the floor area, and regulate the spaces at the front and the back of building. If it is desired to secure a good standard of daylighting, the problem has to be considered in more detail. So also must the existing obstructions be considered, or if there are as yet no obstructions, it is probably wise to assume obstructions up to the limit permitted under the model clauses or bye-laws in operation.

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SECTION X

ELECTRIC LIGHTING

PROBABLY more than half the waking home life of those who go out to work is spent under artificial lighting. This fact gives the measure of the importance of artificial lighting. Always in the past we have been restricted in our freedom of action by the need to adhere more or less to the hours imposed by the rising and setting of the sun. The rapid extension of electric lighting—electricity is now installed in over 75 per cent of the homes in this country—has at last emancipated us.

It would be neither practical nor pleasant to attempt to reproduce in the home at night the conditions which obtain out of doors in daylight. Fortunately, human eyes are compensated in such a way that a reduction of 90 per cent in illumination only halves their vision. Moreover, artificial lighting can be so disposed as to operate at the points at which it is required.

As Mr. Atkinson points out, the normal layout of lighting installations has generally been quite unnecessarily casual and wasteful. Often a substantial increase in lighting efficiency can be achieved by devoting more thought to the location and design of fittings. This improvement normally should be supplemented by the provision of additional points and by increases in the strength of lamps. The author proceeds systematically around the house, indicating what the usual requirements are and how they can best be met.

Domestic fluorescent lighting is still in its early stages. As the cost of power consumed by filament lamps is such a negligible part of a normal budget, and as fluorescent installations are still relatively expensive in first cost, it is doubtful whether the latter are justifiable for domestic lighting on economic grounds alone. Light from a fluorescent fitting is, however, less glaring than that from an unshielded filament lamp ; on these or on other grounds it is likely to illuminate many future homes.

ELECTRIC LIGHTING

By A. D. S. ATKINSON, A.M.I.E.E.

THE NEED FOR ADEQUATE LIGHTING

In the early days of this century, electric lighting at home was regarded as an expensive novelty and was available only to the few, who switched on grudgingly and for as short a period as possible. This attitude, however justified then, is obsolete in these days of almost universal supply; electricity is now installed in over 75 per cent of the homes in this country. The time has come when artificial light need no longer be considered an inferior substitute for daylight, and in some respects it can give a better service than natural lighting. We can control its colour and change it at will; we can use it where and when we like; brightness and depth of shadow are matters of choice. The one remaining restriction is in quantity, for no artificial light source at present practicable for ordinary domestic use can provide the flood of light received near a large window on a clear day.

Probably more than half the waking home life of people who go out to work is spent under artificial lighting. To them, windows to admit light are substitutes for electric lighting fittings, and it is therefore only reasonable to give earnest consideration to a lighting service which will be in continual use for the greater part of conscious home life, and can have such a large effect on comfort and well-being.

Artificial lighting, whether used by itself or to supplement natural daylight, has a number of functions to fulfil. Lighting for preservation of safety, conservation of eyesight and avoidance of unnecessary fatigue concerns health, while lighting for housework and homework, for convenience and decoration affects the ease with which household work is done and the enjoyment of the home. It should be the business of the architect, the builder and the engineer to ensure that the lighting is so contrived that it fulfils all its functions with generosity, and that it is installed (except perhaps in houses of a purely temporary nature) in such a fashion that the occupier can improve and extend it if he so desires without too much interference with the structure. The more modest the home the more necessary is this provision, for while the rich can perhaps afford extensive alterations at a later date, the poor cannot do so.

It is very strongly urged that the complete basic lighting installation of the house should be regarded as one of the normal household fittings in the same way as the provision of the bath, the sink and similar necessities. The builder should in fact *provide and install* lamps of proved reliability

and adequate size in fittings appropriate to the purpose of each room and to the probable nature of the decorations. Householders in general are ignorant of lighting technique and their ignorance has—perhaps accidentally—been exploited in the past by many builders of housing estates. But provision of adequate basic lighting with the house will ensure that the householder is originally given reasonable lighting conditions, and that if he decides to do away with the fittings provided and to use something which may be quite unsuitable, it is by his own free will and he has nobody but himself to blame.

How can light affect us in our homes ?

SAFETY

The number of fatal and non-fatal accidents occurring at home every year is appalling. We know and admit that coal mines are dangerous places, yet there are twice as many fatal accidents in and around the home as in the mines. Not all home accidents, by any means, are caused directly or indirectly by poor lighting, or by lack of any lighting at all at the right time and in the right place ; but a large proportion certainly are so caused. The loose stair rod which is not noticed because it lies in a dark corner ; a child's ball left on the stairs ; the piece of soap left lying on the bathroom floor ; the scalding grease from a pan imperfectly balanced on a dark, though handy, ledge ; the foot caught in a loop of the lead of an electric kettle ; fingers cut when shredding cabbage ; the stumble in the dark when fetching coal from the bunker—all these and many other dangers will doubtless continue, but the regularity and frequency of accidents can be very much reduced by lighting which really enables people to see instead of to guess.

CONSERVATION OF EYESIGHT

Modern civilisation demands from our eyes more than they can give without adequate help. They are now asked to concentrate on small detail at short range from dawn until long after dark, whereas they were evolved for more casual viewing of larger objects, chiefly in the middle or far distance, from dawn to dusk only, and in full daylight. Everyday tasks in the modern home need perfect eyesight (or adequate correction of faulty eyesight by glasses) *and* sufficient light. If the light is wrong, seeing becomes a strain which leads to fatigue and may easily damage the eyes.

Houses fit for housewives to live in should be designed to make the daily work not only easier, but also quicker and more foolproof. This objective requires quick and certain vision at all times and in all places, not only at the sink, work table, and fireside, but also in the corners and

cupboards where dirt and disorganisation are liable to flourish in semi-darkness.

It must also be borne in mind that houses are not built only for those in their early twenties when eyesight is at its strongest. There are youngsters and their homework to consider; young eyes are particularly liable to damage from unsatisfactory lighting conditions, especially at the end of the day when they have been hard at work for many hours. There are also the over-forties whose eyes are deteriorating and who need more light as they get older. How many times have we heard the remark "It'll have to wait until tomorrow; I can't do it in this light."

The extent to which artificial light is provided must of course be a compromise between what may be theoretically desirable and what is economically and practically possible. Theoretically, one might desire to provide perfect seeing conditions such as are only possible under the high lighting intensities of outdoor natural daylight or just inside a large window on a bright clear day. Here there will be some 200 foot-candles illumination; to provide this after dark over the whole area of a living room of about 180 sq. ft. would need (with ordinary gas-filled lamps) a lighting installation totalling some 10,000-watts—which of course is absurd. The heat would be unbearable, and the expense prohibitive. Even with fluorescent lamps such an illumination is not practicable over large areas in homes, nor fortunately is it necessary.

Human eyes work in such a fashion that a reduction of 90 per cent in illumination approximately halves the visual performance. If we are content at the present time to accept this halving of daylight performance (and we obviously must accept some reduction) then we need only provide an illumination of the order of 20 foot-candles. Nor is it necessary to have this throughout the house; the general lighting of rooms can be on a still lower level, provided that the necessary extra light can be available at the places where specially difficult seeing tasks are normally undertaken.

But it should be understood that the old order of house lighting is not good enough for modern days. The usual maximum illumination of about 5 foot-candles, as is given by a single lighting fitting with a 60-watt or 75-watt lamp in the centre of a living room, is neither sufficient nor economical. Sooner or later the occupiers will realise this and will want to improve on it, and if the house has been planned with forethought they will be able to do so with no great trouble or expense.

BASIC REQUIREMENTS OF THE LIGHTING INSTALLATION

The first and most obvious requirement is that there should be sufficient light in the right place. Standards of sufficiency are constantly being improved through experience of higher lighting levels in shops, cinemas, factories and offices, and any recommendations made here are liable to

revision as time passes, as lamps become more efficient, and as the cost of current decreases. Broadly, one may assume that five different minimum illumination ranges may be required :

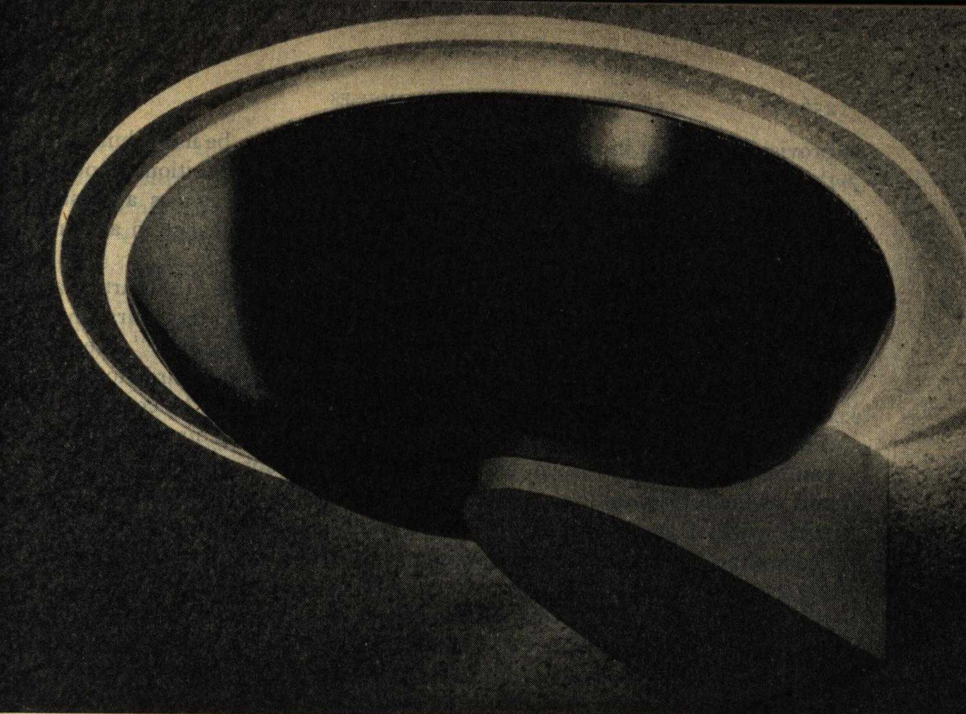
(1) For safe movement, as in corridors and on stairs (2–4 foot-candles).
(2) Where subdued lighting may be æsthetically desirable, as in a dining room (4–6 foot-candles).
(3) General utility lighting for ordinary household purposes which do not demand specially good definition of detail (6–10 foot-candles).
(4) A higher level for detailed tasks such as ordinary needlework, reading and homework (10–15 foot-candles).
(5) A still higher level for sewing dark goods or reading fine print (15–25 foot-candles).

Of course, it harms no one to have more light than this minimum, though for economy's sake one would not wish to provide a high level of lighting where it is not required. On the other hand, where doubt exists it is better to err on the side of abundance than of parsimony.

Generally, the position of special features which will require particular lighting attention can be predicted in the average home. They are the fireside area of the sitting room, the dining table, the kitchen cooker, sink and work table, the dressing table and bedhead, the shaving mirror in the bathroom and the treads of stairs. On the other hand, it is possible that occupants may desire to change over, say, the dining and sitting rooms ; there is also likely to be a periodical rearrangement of furniture. It is therefore suggested that in most cases the dining room installation should be identical with that of the sitting room, and that bedhead and dressing table lights be provided from plug points conveniently situated round the room, and not by fixed ceiling points which may in effect dictate too rigidly the position of furniture.

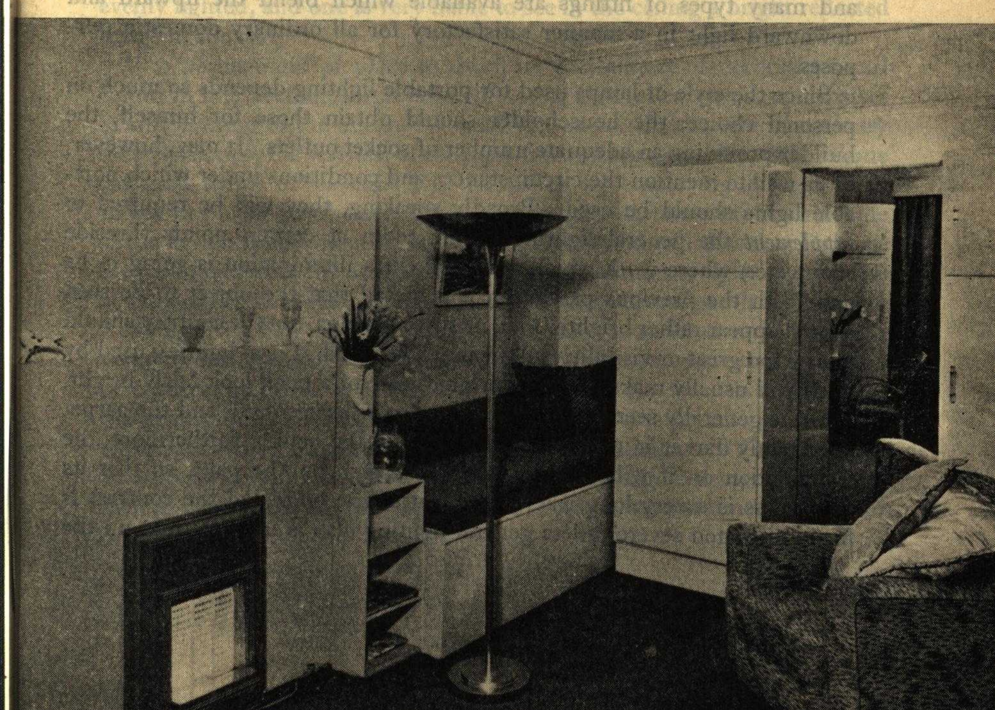
QUALITY OF LIGHT

Laymen often associate plenty of light with bright lights and a fun-fair atmosphere, which at home is neither necessary nor desirable. It is a simple matter to provide all the light required in a soft and pleasant manner, without dazzle or glare. It is chiefly a matter of recognising the obvious fact that electric lamps are not sufficiently beautiful objects to be displayed to the view and that most of them are far too bright to be looked at direct without discomfort. The light has to be screened or softened to make it acceptable, even in some cases when fluorescent lamps are used. That is the chief purpose of domestic lighting fittings ; they may also be decorative, but that function is secondary to the main one of making the raw light pleasant to live with and directing it to the areas where it is chiefly required. It is recommended (page 259) that domestic lighting fittings should not exceed a certain brightness in order to avoid glare ; this



181. A wall bracket with surrounding glass ring etched to appear luminous. This adds vitality to an interior which might appear monotonous with indirect lighting alone.

182. An indirect floor standard can, with a large enough lamp, provide sufficient light for a complete interior, but additional self-luminous features in the room are desirable to add interest (see above).



provision does not in any way limit the size of lamps to be used, but only the brilliance of the fitting as seen from a normal viewing position. Though some may appreciate the lively sparkle of an object such as a crystal chandelier, a fixed and permanent point of extreme brilliance in a room becomes irritating and distracting.

One of the major rules of lighting is that, in general, the particular objects we want to see should be made rather brighter than their surroundings. It is evident that one way of ensuring this is to use a form of " direct " lighting whereby all the light is collected and thrown downwards towards the table, the book or the other object with which we may be concerned. This, however, has the effect of leaving the ceiling and upper walls in comparative darkness which, besides giving an atmosphere much too hard and severe for domestic purposes, results in the lighting fitting appearing even brighter and more glaring than it really is, owing to it being seen against the dark ceiling. The opposite effect, given by " indirect " lighting, has often been claimed as ideal, but with this system, which throws all the light upwards to the ceiling from whence it is redirected downwards, the ceiling almost certainly becomes the brightest object in the room and tends to distract attention from where it is needed. Further, indirect lighting uses more current and is thus more expensive than direct lighting giving equal illumination. It also tends to become flat and monotonous at moderate and low levels of illumination, owing chiefly to the very even lighting effect reducing those contrasts of light and shade which give life and interest to the surroundings. Neither system used alone is therefore likely to be very satisfactory, but a combination of the two can be ideal, and many types of fittings are available which blend the upward and downward light in a manner satisfactory for all ordinary domestic purposes.

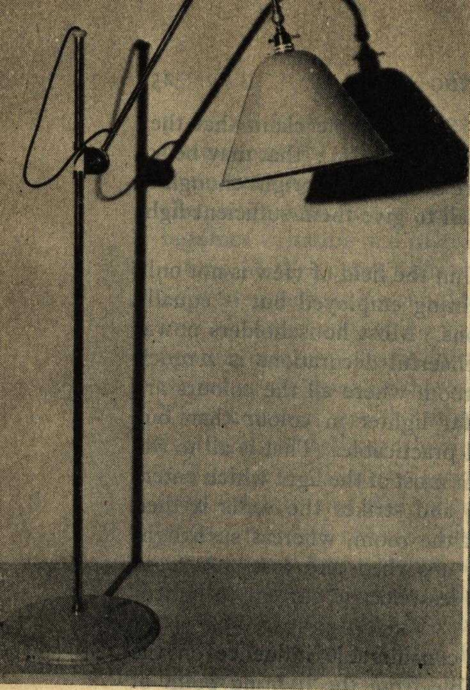
Since the style of lamps used for portable lighting depends so much on personal choice, the householder should obtain those for himself, the builder providing an adequate number of socket outlets. It may, however, be as well to mention the circumstances and conditions under which portable lights should be used. Broadly speaking, they will be required to *supplement* the general lighting of the room at certain points (fireside chair, etc.) where work which demands extra illumination is going to be done. In the previous paragraph it is stated that the object to be seen should appear rather brighter than its surroundings, but the contrast should not be too great or visibility will be much reduced. Local lighting used by itself will usually make, say, the printed page of a book look fairly bright, but it is generally seen against the carpet as a background, and the carpet is certainly darker in colour than the page of the book ; furthermore, the illumination on it will be very much less than on the page, so that its brightness is a very long way below that of the book and the contrast is likely to be too severe unless general lighting also is used to light up the

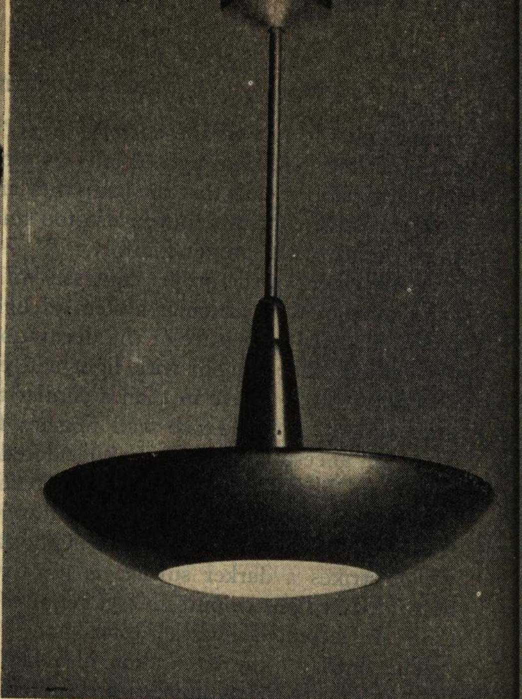
carpet and the rest of the surroundings. Some people claim that they prefer sitting in a room lighted only by a portable lamp ; that may be so, but it probably means that the lamp they are using is not bright enough to give excessive contrasts, but is also too small to give them sufficient light to do their work in proper comfort.

Achievement of the proper contrasts within the field of view is not only a function of the particular system of lighting employed but is equally determined by the nature of the decorations. Most householders nowadays realise that a room with light and cheerful decorations is a much pleasanter place to live in than a similar room where all the colours are drab and dreary, and use wall finishes far lighter in colour than our Victorian ancestors would have considered practicable. That is all to the good from the lighting point of view also, for most of the light which enters the window or leaves the lighting fitting and strikes the walls is then reflected back and distributed throughout the room, whereas such light which strikes a darker surface is mostly absorbed and lost. A room decorated in light colours in fact requires less electric current to light it than one decorated in darker tones.

The finish of the decoration also has considerable influence on the lighting effect. Matt finishes are preferable from the lighting point of view since they show no highlights, and any fortuitous sudden change in the candle-power of the fitting at slightly different angles will be largely camouflaged, whereas with glossy finishes annoying highlights, e.g. reflection of the fitting, can be seen in the walls. A glossy ceiling is particularly objectionable, as it is extremely difficult to make it appear evenly lighted, and one is very liable to see in the ceiling a bright reflected image of the lamp.

It is perhaps out of place to dwell on the subject of decorations and colour in this Section, but it is worth noting that it is a very simple matter to suit lighting to the decorations and vice versa. In the case of ordinary filament lamps, the warmth of the light can be varied by using either flame coloured lamps or daylight blue lamps, or by employing fittings of an amber or bluish-green tint. These expedients will, however, absorb some of the light originally generated by the filament and will therefore increase the running cost of the installation for a given amount of light. In the case of fluorescent lamps we already have two alternatives, one lamp giving a " daylight " colour of light which is generally considered rather cold for living rooms, but may be very suitable for the kitchen where an appearance of coolness is often to be desired ; the other gives a " warm white " which emphasises the warm tones and colours and is generally considered to be much more suitable for the other parts of the house. The two types of lamp are completely interchangeable, and the colour change is obtained with no loss of efficiency, which in both cases is several times that of the corresponding filament lamp.

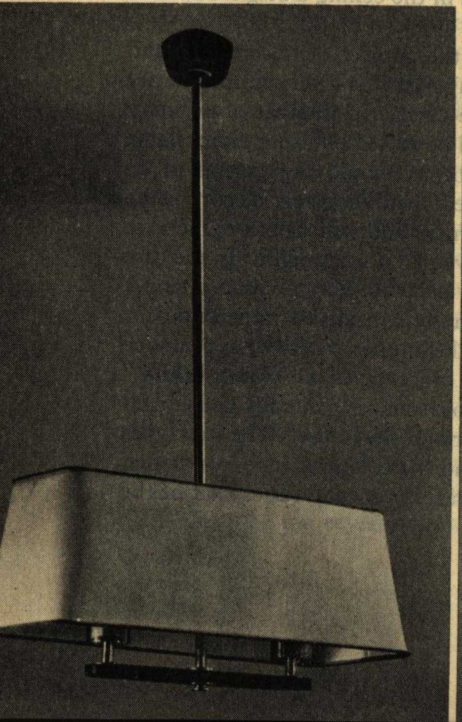




183. A style of "bridge lamp" for use where the pedestal must be at a distance from the actual source of light, as for a card table.

184. The main "working" light comes from the circle of diffusing glass below, while upward light illuminates the ceiling.

185, 186. Fittings, suitable for a dining room, concentrate most of the light on the table beneath.



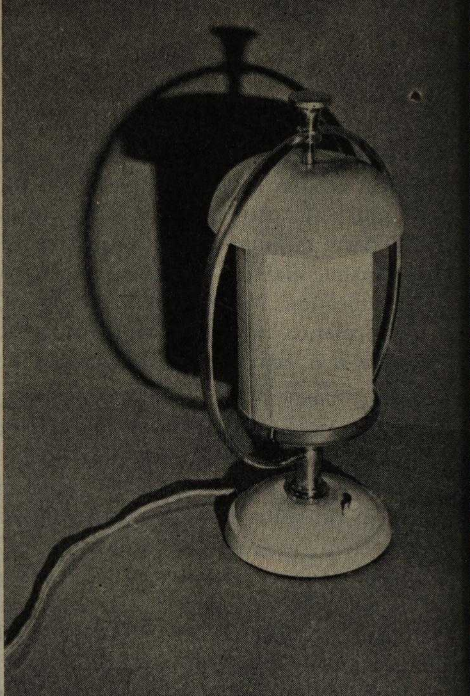
RECOMMENDED LIGHTING INSTALLATION

The following suggestions are based on the *minimum* requirements of small houses likely to be occupied by people with limited income, and should obviously be more comprehensive in the case of larger and more elaborate buildings. In making the recommendations it is assumed that Tungsten filament lamps complying with the current British Standards Specification 161 will be used, or Fluorescent lamps with equivalent performance, and that the lighting fittings will comply with any appropriate B.S. Specification which may be issued.

Living room

Only the occupant can decide what type and style of lighting fitting he wants, particularly in a living room, but care should be taken not to encourage the use of fittings which will obviously give unsatisfactory service in some respects. The general public has not yet learned that electric light need not and should not be glaring, and if they are given a chance they will as likely as not choose glaring fittings simply because they know no better. It is therefore suggested that no fittings for any of the main rooms should be contemplated which have a brightness greater than 10 candles per sq. in. over the 0–60° zone from the downward vertical, but this should not debar the use of prismatic glassware, small areas of which may operate at a greater brightness. This provision would effectively prevent a direct view of glaring brightnesses at normal viewing angles—in fact it would eliminate the familiar shallow conical shade—but would not affect the brightness or quantity of the light thrown in an upward direction and needed for the illumination of the ceiling. It is also suggested that the luminous efficiency of the fitting (i.e. the proportion of the original lamp light which eventually emerges) should not be below 60 per cent unless efficiency is purposely sacrificed for decorative effect, in which case the wattage used would need to be increased above the figures given below. Any fittings manufacturer of repute should be able to supply data regarding both the brightness and efficiency of his fittings.

In a living room the fireplace, where one is fitted, becomes the centre of interest for the greater part of the year, and a ceiling fitting might well be placed to serve the fireside area. In long rooms or where the fireplace is at one end of the room it may of course be necessary to use two such fittings. Where there is no focus of interest, as in rooms heated by other means, there is justification for increasing the number of lighting plug points beyond the three that should normally be installed (any two of which would generally be available at one time for lighting, with the third for radio, fan, etc.) for the furniture will probably be turned to face the centre of the room and fixed lighting, either on the ceiling or walls, tends to shine in people's eyes, whereas the position of portable lamps can be rearranged as required.

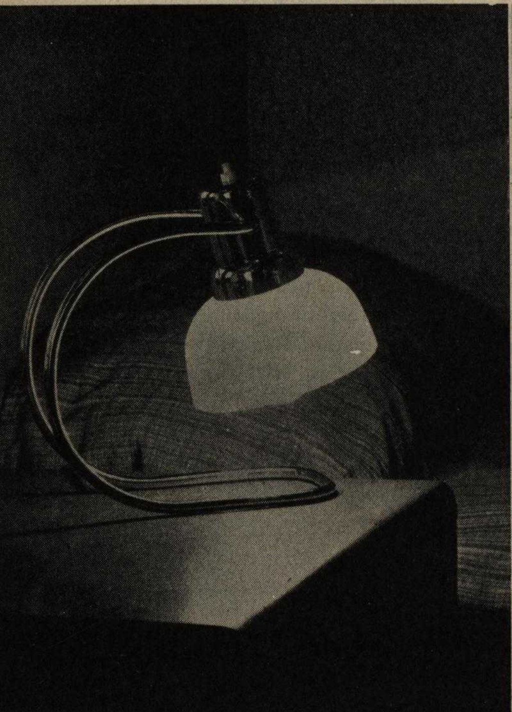


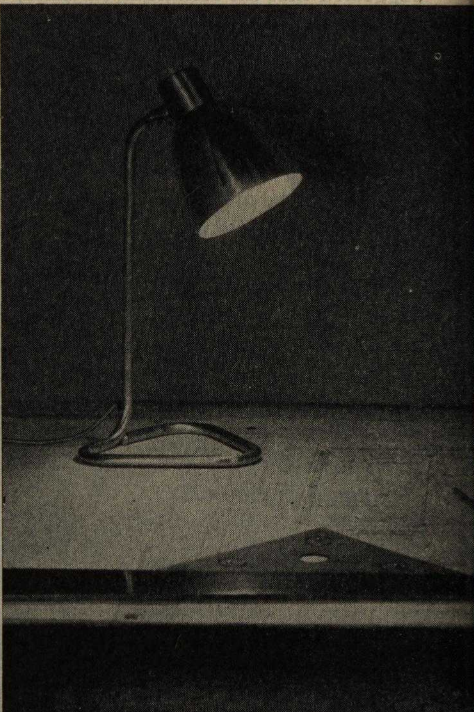
187. Small moisture-proof opal glass fitting for 40-watt or 60-watt lamp, which is easy to keep clean and suitable for bathroom and over-sink position in the kitchen.

188. This bedlamp is fitted with a swivelling shade, which can distribute the light in one or two directions as required and is thus suitable for use between twin beds.

189. Bedlamps of this nature can be very satisfactory if the shade is comparatively opaque and thoroughly screens the lamp. The switch should be within easy reach of the bed.

190. A portable local light of this type may give rise to reflected glare. It should be used with care, and only as a supplement to general lighting.





The minimum size of lamps which should be used for fixed lighting depends mainly on the type of fitting chosen, the size of the room and the nature of the decorations. Assuming the last to be reasonably light in colour, in very general terms there should be $\frac{3}{4}$-watt of lighting per sq. ft. of floor area if a type of fitting is used which directs most of the light downwards; $1\frac{1}{2}$-watts per sq. ft. if a fitting directs most of its light upwards, and 1-watt per sq. ft. if it is of an intermediate type. It is strongly recommended, however, that reference be made to the appropriate section of *Post-War Building Studies* No. 12 (H.M. Stationery Office) or to the *Code of Practice for the Lighting of Dwellings*, Chapter VIIA (at present in draft form) since the minimum lamp sizes given therein may become mandatory.

Portable lamps

Though portable lamps are normally regarded as part of the furnishings of the house, for which the occupant must be responsible, it is perhaps worth noting that the table lamps usually employed may often be decorative but generally have very little utilitarian value as sources of light. The Study Lamp, covered by B.S. 710, can be strongly recommended, as it not only gives a guaranteed illumination in a downward direction sufficient for most detailed tasks carried out at home, but also permits a reasonable quantity of light to go upwards towards the ceiling, thus lighting the rest of the room and reducing the contrasts which might otherwise be objectionably high.

Working kitchen

If sufficient lighting is provided by ordinary means on the cooker, the sink and the work table, illumination of the rest of the room is almost automatically looked after, but proper lighting of these three places can hardly be achieved without using at least two fittings, one of 40-watts over the sink, and the other of not less than 60-watts (or 75-watts if the floor area exceeds 120 sq. ft.) for the other important parts. The fittings used should be either dust-tight or so designed that they do not trap any moisture that tends to collect on account of the greasy and steamy atmosphere. Ease of access for cleaning is of course an important point, and it is reasonable to demand a minimum luminous efficiency of 70 per cent with at least half the light output going downwards and at least a quarter upwards. Most of the popular " enclosing " types of opal glass fittings would meet the above requirements. In kitchen-living rooms the main fitting should be chosen as for the living room, with an extra fitting for the sink or cooker.

Bathrooms

In general a 60-watt lamp in a fitting similar to that used for the kitchen and mounted so that the light falls on the face of a person using the mirror (if the position of this can be predicted) will be sufficient. Fittings should

not be suspended on flexible cord and the switch should be placed outside the bathroom or operated by a cord from the ceiling.

Bedrooms

As noted earlier, it is likely that any attempt to provide adequate illumination at all the important places by means of fixed lighting points will have the effect of anchoring the furniture in certain positions which the householder might wish to alter. On the other hand, if lights other than the main ceiling point are to be supplied from plug points it means that a complete lighting service would probably not be available to the occupier until he could or would purchase the necessary equipment himself. It is perhaps a matter which could best be decided on site.

There must of course be a main lighting fitting for reasonable convenience and for seeing into cupboards, etc., and a position near the middle of the ceiling is usually the best for it. It has been suggested that when the position of the dressing table can be foretold this light should be placed so as to serve the dressing table mirror also; but it is very doubtful if this is generally feasible, since to be effective a mirror light must be in front of the face of the person using it, i.e. so far towards the window or wall that it would not give very much illumination in the rest of the room.

Nothing less than a 60-watt lamp should be used for the main light. Where the room is of more than 120 sq. ft. area, or if the fitting throws most of its light upwards, this should be increased to at least 100 watts.

At least two lighting plug points should be provided (or at least one if the bedhead light is in a fixed position and the dressing table served by the main light). It should be noted that the bedhead light should not hang from the ceiling and shine straight in a reader's eyes; it should be fixed to the wall above and behind the bed, or fixed to the bedhead itself and supplied from a plug point. The switch should be within easy reach of anyone lying in bed.

Halls, Stairs and Landing

It has been recommended that lights on staircases should be so arranged that each tread throws a shadow covering between half and three-quarters of the tread below, but this may be a difficult matter to arrange, especially if there is a turn in the stairs. The best location of the fittings must depend upon the plan of the house and the most that can be said is that there should be an obvious difference in brightness between the edge of a tread and the surface of the tread below. A pile carpet will usually help by accentuating any such difference. Generally a safe degree of visibility will be obtained by a 40-watt lamp placed near the head of the stars and another near the foot, both controlled from near the top and bottom of the stairway. More often than not these lamps will also serve the landing and hall, but if not, the landing light should be placed conveniently for seeing into any cupboards that may be there. The light at the foot of the stairs

should be of such a type, in such a position, or of such low brightness in an upward direction that it cannot dazzle anyone descending the stairs.

General

Front and back doors should have an exterior light since it is not generally the case that adequate illumination is otherwise provided on the threshold, e.g. by light passing through glass panels in the doors. The latter arrangement is very unlikely to provide safe conditions on steps outside the doorway, or to make identification of the house easy by lighted number or name ; nor would it generally light the coal bunker or the way to the garage.

The garage itself should have at least one lighting point (100-watt) and one lighting plug point for a portable lamp. Special consideration should also be given to the various built-in cupboards in the house which, if not adequately lighted by daylight or by the nearest artificial lighting point, will require a light of their own, controlled perhaps by the opening and shutting of the door. If there is a loft or an attic it can become a far more useful place if one or more lights are provided there.

ARCHITECTURAL LIGHTING

The preceding paragraphs deal with the minimum installation reasonably satisfactory for a small home occupied by people with shallow pockets and no great pretensions, but the use of fittings fixed to or hung from the ceiling is a habit learned in the old days when artificial lights were flame sources. Lighting fittings in general are dust collectors, either internally or externally, but luminous panels need not suffer to nearly the same extent, with the result that they can retain their clean and neat appearance for relatively long periods.

Nowadays there are practically no limits, other than economic ones, to prevent the installation and use of electric light how, when and where it is most convenient and suitable. Lighting can now become part of the structure, and even before 1939 there were a number of houses well below the £1,000 class with built-in panel lighting of one form or another. Doubtless these ideas were then introduced largely as an extra selling point likely to influence prospective customers, and the need for such features may not be so apparent to builders in the immediate future when they can dispose of almost anything with a roof and a front door. Nevertheless, it does show that modern forms of lighting were welcomed in the past, and there is every reason to suppose that, as appreciation of good lighting grows, they will be even more warmly welcomed in the future.

Lighted panels are generally designed to appear equally bright over the whole luminous surface. If that is so, flashed opal glass should generally be used with the recess in which the lamps are fitted painted matt white. Lamp spacing in either direction (measured from the geometrical centre

of the filament) should not exceed their distance behind the glass for the measured brightness to be even, but inequalities of brightness will not usually be apparent if the spacing is increased by up to 50 per cent. The size of lamps used will not affect the spacing, but it is suggested that the panel brightness is likely to be excessive in an ordinary room if more than $1\frac{1}{2}$-watts of lighting is provided per sq. in. of glass surface. Pearl lamps should always be used.

Frosted, figured and rolled glasses can also be used to give more sparkling effects, but if even brightness is to be obtained the depth required behind the panel will have to be very much greater. Its use is not generally recommended, therefore, unless a grille or some other device is used to cover the darker portions of the glass, and to break up the surface so that inequalities of brightness are not readily apparent. Something of this nature may also be required to conceal the dark patches at the ends of fluorescent or filament tubular lamps arranged in continuous lines.

Ventilation of enclosed elements of this nature is not usually necessary, as there is generally sufficient glass area to radiate the heat generated within the enclosure. This is fortunate, as total enclosure excludes dust. There should of course be easy access to the lamps for replacement, and the lamps should not be fitted closer than 1 in. to woodwork or other inflammable material.

Cornice lighting often fails to provide the lighting effect it should, because the cornice is too close to the ceiling and the lamps too close to the wall. To give a good lighting effect on the ceiling a cornice should be at a distance below it at least equal to one-third of the width it is required to serve, unless accurate light-controlling equipment is used. Thus, if the room is 15 ft. wide the cornice should be at least 2 ft. 6 in. below the ceiling if the room is lighted from both sides.

A gently curved junction between the ceiling and wall improves both the illumination and the distribution of light over the ceiling, which should have a matt or at least an eggshell finish to avoid specular reflection of lamps, and must, of course, be very light in colour.

If the frieze is to appear evenly lighted and if ordinary gas-filled lamps are used, they should be spaced at a distance apart not exceeding $1\frac{1}{2}$ times the distance of the geometrical centres from the nearest part of the wall just within sight above the cornice, otherwise spottiness may be apparent. Generally, however continuous " line " sources such as fluorescent tubular or tubular filament lamps will be used.

It is impracticable to give detailed information regarding the relative wattage necessary with panel or cornice lighting since it will depend to some extent on where and how the particular lighting feature is used, but in very general terms about twice as much wattage will be required as for a " mainly direct " fitting used on the ceiling and equipped with the same class of lamp. In this connection it should be borne in mind that the

relative efficiencies of vacuum tubular, gas-filled and fluorescent lamps are *roughly in proportion 1 : 2 : 4. A fluorescent cornice might therefore* replace gas-filled lighting from the ceiling giving equal illumination at about the same cost for current.

ECONOMICS

In conclusion it will be worth putting the cost of adequate domestic lighting into proper perspective in relation to some of the other costs considered reasonable or essential by the average householder.

In the ordinary small home, if the foregoing lighting recommendations are followed, the average consumption of current for lighting throughout the year will be at the rate of, say, 5 units per week. If the house is supplied with electricity on the two-part tariff the cost per unit (nearly always a penny or less) is so small that the weekly expenditure on lighting is negligible. If electricity is supplied on a flat rate of the order of 4d. per unit, the weekly cost then works out at rather less than that of a single packet of cigarettes, or less than half the weekly expenditure of most families on the cinema, or the cost of insufficient beer to quench even one ordinary thirst for very long. These examples may be classed as necessities or amenities according to the point of view, but nobody who indulges in them can justifiably complain of the cost of proper lighting.

As far as installation work is concerned, here again there is generally an exaggerated idea of the cost. Before the war the average rural three-bedroom parlour house of a little less than a thousand square feet area had an unsatisfactory and insufficient lighting system which cost some £11 to install (excluding allowance for overheads or profit). An installation for the same house equipped as suggested earlier in this section would, in 1938, have cost some £15 plus the cost of fittings and lamps—or in other words, something of the order of 5 per cent of the total cost of the building.

This percentage is likely to remain substantially the same after the war, and it is ridiculous to install an unsatisfactory lighting service which will be a constant cause of complaint, when a perfectly satisfactory one will only add some 2 per cent or 3 per cent to the total building cost.

It is a little early yet to attempt to estimate the probable cost of fluorescent lighting, beyond repeating the broad statement that the running cost for a given quantity of light is likely to be rather less than half the cost of lighting by gas-filled filament lamps. Against this saving must be set the greater cost of the lamps themselves and the capital cost of the control gear required. At present there is only an 80-watt lamp, 5 ft. long, available in two colours, which is perhaps not entirely suitable for most domestic purposes on account of its length. Shorter lamps of lower wattage will certainly be available in future, but it is not yet known what their cost or that of their auxiliary apparatus will be, and whether fluorescent or

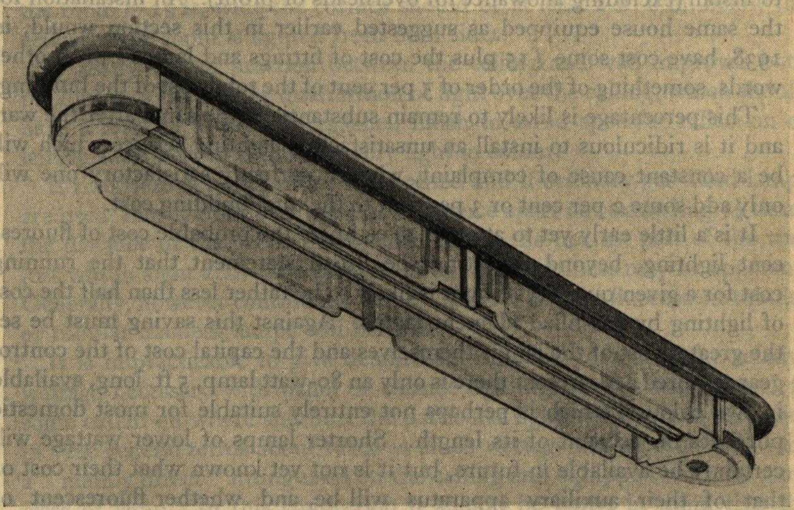
ment lighting will be cheapest will evidently depend largely on this and on the cost of electricity.

There is little doubt that if current is bought on a flat rate of about 4d. per unit, fluorescent lighting will be cheaper in the long run, but on the two-part tariff with a secondary charge of a 1d. per unit or less, there is not likely to be much in it one way of the other, assuming of course, that fluorescent lamp efficiencies at present attainable are not materially increased—as indeed they may be, for research is continuing energetically.

However, it is really of little interest whether this or that form of lighting is cheapest, for as mentioned above the cost in relation to other necessities and amenities of daily life is so small anyway that it is hardly worth bothering about. Fluorescent lighting is certainly the most up-to-date method, but there may be some conservative elements among us who would prefer something with which they are more familiar. The choice is free.

There is no doubt, however, that although a large proportion of prospective householders may not be quite sure whether they prefer fluorescent lighting on grounds of economy, lack of shadow, softness or colour of the lighting, or merely for its novelty, they will nevertheless demand it, and builders would be wise to bear this in mind.

191. A fluorescent lighting fitting suitable for a large interior. Designed to fit flush on the ceiling, it may house 1, 2 or 3 lamps, each in this instance being 5 ft. long and consuming 80 watts. Uncoloured glass is used here, but plastic materials would also be appropriate.



SECTION XI

HEATING

We in England have achieved notoriety throughout the world for the coldness and dampness of our homes. While others living in more extreme climates have been perfecting methods of indoor heating, we have been content to huddle over our point sources of heat and to endure quite unnecessary discomfort in the rest of the house. The remarkable fact is that in our discomfort we are consuming fuel at a far higher rate than in most other countries. The old-type coal fire is a supreme example of the power of sentiment over reason. For the sake of its flickering light we are willing to contaminate the atmosphere of our towns and to squander our dwindling supplies of coal.

Mr. Fischer in his Paper runs through the long list of types of heating appliance from which we are able to choose, indicating the advantages and disadvantages of each. He has reached the conclusion that District Heating—the supply of heat from central boiler stations—is a method which is likely to find widespread favour in the future, and he expands his reasons for believing so. District heating is competitive in cost to the consumer, and even more economical in fuel; it saves trouble to the householder and space in his house which would otherwise be taken up by flues and fuel stores; it can help to protect our towns from the expensive and unhealthy scourge of smoke. His argument includes an analysis of the relative costs.

The author ends with a discussion of the future of the heat-pump, the most revolutionary of the new heating devices. He is inclined to believe that—at least for some time—it will not play a major part in supplying our homes with heat.

HEATING

By L. J. FISCHER, DIPL.-ING., A.M.I.MECH.E., M.I.H.V.E.

WARMTH in our houses is not a luxury. Without protection the human being is not equipped to resist cold and humid weather. Twentieth-century man is neither degenerate nor soft ; in fact, his physical stamina and mental fitness seem greatly to exceed those of his forefathers, when measured by his achievements. Yet these achievements themselves reflect man's growing mastery over his natural environment. The provision of artificial shelter and of artificial warmth allows him to direct his energies into more positive channels.

WHY DO WE NEED HEAT?

It is not intended here to attempt a complete answer to this question ; it will suffice to state two vital physical reasons why the human body needs protection against cold. Every object which is warmer than its surroundings will lose heat energy towards the cooler medium. Similarly an object cooler than its environment will increase its heat content. If the surface of a body is wet the surrounding air, if not already saturated with moisture, will tend to absorb in vapour form the humidity of the surface, thus extracting from the warmer body a large amount of heat for the process of evaporation. An inert object can exist at any reasonable temperature, although its state may be influenced by the temperature of its surroundings ; in contrast, the human body within certain margins, reacts physiologically against too low or too high temperatures. As an energy producer it is only comfortable when its own temperature is at the correct level ; if this temperature is too low the human machine gets overloaded by the necessity to produce the extra heat to restore body temperature ; if too high, discomfort is produced because heat generated in the chemical transforming process cannot be disposed of quickly enough. There are analogies to this in the mechanical world ; the internal combustion engine requires heating up in cold weather before running smoothly, and the high tension electrical transformer needs cooling for the removal of the heat energy released in the process of voltage transformation.

FORMS OF HEAT TRANSMISSION.

Heat can be transmitted to the human or inert body or removed from it in three distinct ways ; in practice any heating or cooling apparatus

combines all three forms, though with emphasis on one. The heat emission (loss) or the heat absorption (gain) can be by *radiation* ; in this form heat rays leave the object or are absorbed by it without contact between the source and the receiver. The warmth of the sun is an example of this process. Where the heat is transmitted from surface to surface, e.g. along materials by contact, we speak of *conduction* ; thus, the poker handle gets hot if the poker is in contact with hot coal, or a warm bottle is cooled by immersion in cold water. The hot water bottle is a heating device which provides heat by conduction. The third and most frequent way of transmitting heat is by *convection*, i.e. by using a fluid—either liquid or gas—as a transmitter. In this case the particles move to and fro between the source and the receiver, and thus continuously redistribute heat energy. The air warmed by the so-called radiator or by the closed stove tends to rise and thus to set up circulation inside the room, until it loses its heat content in warming up the cold surfaces of the room. To some extent the open fire works in this way. Cooling coils in a refrigerator are an example of the same process in reverse.

HEAT AND COMFORT

The human body has an average surface temperature of 93° F. which has to be maintained whatever the temperature of the environment. In a cold atmosphere the naked body quickly loses its heat by radiation ; after a few hours the heart ceases to function and death occurs by chill. Clothing protects the body against quick heat losses in cold surroundings, but it cannot maintain body temperature without continuous heat supply when the atmospheric temperature gets too low. The extra heat required must be provided by an outside heat source or by the body itself producing more ; thus in winter we keep warm by artificial heating or by manual work. The heat equilibrium, i.e. comfort, will be achieved where the heat loss of the body equals the heat gain. Sedentary work may be unnatural, but we have to allow for it ; in doing so we must resort to artificial heating.

There is not only a lower limit of atmospheric temperature beyond which discomfort is caused ; an upper limit is also soon reached. The body requires to be kept in an atmosphere cool enough to allow it to give off heat and is uncomfortable if surrounded with air at body or even at skin temperatures. Investigation shows that room temperatures have to be in the region of 65° F. to give us this feeling of comfort.

There is another element to be considered. It will be found that in some localities a high air temperature gives less comfort than a low one. The reason for this sensation, taking the ventilation conditions as equally favourable, is found in the fact that in the former case—high room temperature—the wall temperatures are fairly low, whereas in the second

instance, in spite of low room temperatures, the wall temperatures will be comparatively high. In this case heat loss due to conduction may be high, but at the same time heat loss due to radiation is low owing to the higher temperatures of the walls. Thus a heating system has to take into account the temperature both of the atmosphere and of the wall surfaces.

In practice, a good heating system must provide for heat-retaining walls, and must keep their surfaces warm. Moreover, a heat source is needed which emits heat that can be felt anywhere in the room and which creates convection currents that avoid cold draughts from windows and outer walls.

Nearly all modern heating systems originated in Great Britain. This statement can be substantiated by reference to James Watt (1736–1819), the father of the steam engine and thence of steam heating : to the American Angier March Perkins (1799–1881), who arrived in this country in 1827 and soon afterwards evolved the first hot water heating system : to the Scotsman William Murdoch (1754–1839), who in 1803 pioneered the utilisation of gas : to Messrs. Wattson and Slater, who in 1852 patented the first electric fire. In recent years panel heating was invented and first applied in this country.

METHOD OF HEATING

The choice of heating appliances will largely depend on the use to which the rooms are to be put.

Space only used occasionally or even only for a short period in each day will need an apparatus capable of rapidly supplying heat. Quick heating up and quick turning off of heat is in such cases both a convenience and an economic asset. This is known as intermittent heating.

Rooms in continuous use and which need continuous warmth lend themselves to a heating method which works at a high thermal efficiency and uses cheap energy ; the length of period for heating up and cooling down and first costs are of major importance. This form is called continuous heating.

For domestic premises a special form of heating is recommended ; this supplies to the whole premises a basic amount of heat which keeps the air and the building surfaces continuously above condensation temperatures. Known as background heating, it involves the maintenance of a temperature range between 50° and 55°F. It is of course supplemented in rooms used for living purposes.

TEMPERATURE DISTRIBUTION

The room temperature achieved by heating may or may not be evenly distributed. If the source of heat is placed at or near the point at which the

greatest heat loss occurs it will warm cold air as it enters and the other parts of the room will remain warm. Heating appliances under windows, or at least on outer walls, are thus more effective than those located in internal walls. Stoves and open fires tend to be confined to internal walls as they need well-protected chimneys in order to maintain the draught. Top-lit ceilings may also require special attention though the problem is eased by the fact that heated air will always tend to rise towards the ceiling.

Radiant heating devices reduce the necessary room temperature as they throw direct heat onto the occupant. In some cases, however, radiant heat may cause discomfort by coming only from one direction.

CONDENSATION

Condensation is not only a nuisance but also, by soiling fabrics and wallpaper, by warping woodwork and by creating conditions favourable for mildew, leads to rapid deterioration. Unheated bedrooms get damp in winter, and no amount of airing will eliminate the danger to health through rheumatic diseases, inflammation of nerves, etc.

The climate of this country is mild, but, due to its island position, humidity is higher than in any continental country. Condensation can be avoided, but its presence and its dangers are seldom sufficiently recognised. Two forms should be distinguished ; one occurs when the outdoor temperature rises and the other when it drops. It must be remembered that air always contains water vapour, the proportion of which is limited but increases with the temperature. When fairly humid warm air is cooled down, some of its moisture content is deposited in the form of water droplets ; on the other hand air when heated up will greedily extract moisture from all humid sources around it, thus drying out their surfaces. The walls of a room which has no artificial source of heat are bound to respond to a fall in outside temperature. They will in turn cool the inside air until it reaches moisture saturation point, below which any extra vapour will condense on the cold walls. This effect is less marked if the room air is not stagnant but is continuously replaced by cold outdoor air, which, except in wet weather, is not fully saturated. Under these conditions, condensation will not occur, as the wall temperature will remain slightly above the air temperature, the temperature of the cooling medium ; in this way airing to a certain extent helps to get rid of dampness.

Alternatively, when outdoor temperatures are rising after a cold spell it may happen that the walls are cooler than the warm outside air. As long as the air is stagnant, nothing will happen, but as soon as the indoor air is replaced by outdoor air, part of the vapour content of the latter will condense on the cold inner surface of the walls. Both forms of condensation are avoided where the space is kept tempered by background heating.

VENTILATION BY HEATING APPLIANCES

Closely linked with heating is the question of air renewal and ventilation. It is often said in favour of heating apparatus with chimneys that they help to renew the air and foster ventilation ; while this is true the chimney provides a somewhat hit-and-miss method of ventilation. When the fire is not lit the quantity of air dealt with is insufficient ; when the fire is burning fast, ventilation may be excessive.

It is clearly true that ventilation can best be achieved by the use of devices designed for the purpose ; these will not be influenced by the draught created in the chimney, which is greatest during the coldest period of the year, just when the introduction of cold outside air is least desirable.

It is frequently believed that the sensation of dry air on centrally heated premises is due to lack of ventilation. This is not the case ; the cause is the drying effect of continuous heating and the more even distribution of warm air throughout the room, and dryness of air can easily be remedied by the fixing of water containers or trays to the radiators. Experience shows that the sensation of freshness depends more on the air movement within a room than on the air-intake from outside.

CLASSES OF HEATING APPLIANCE

(1) *Room heating appliances* are those which supply heat only to the space in which they are placed. These are : open fires, stoves, electric fires, gas stoves, paraffin stoves and similar appliances.

(2) *House heating appliances* provide warmth in a number of rooms and may also contribute heat to ancillary rooms with no special heating apparatus, except for hot pipes leading to the main heating points. This class comprises all types of central heating from individual storey heating to district and town heating ; it also includes combined stove heating and ventilating plants by which warm air is distributed through the whole house.

(3) *Combined room heating appliances* include such devices as : closed stoves built into partitions with part of the heating surface exposed in adjacent rooms, or stoves with smoke flues incorporating heating plates which transmit heat to the rooms through which they pass.

Fireplaces with back boilers and kitchen ranges with heating bottles can also be counted under this heading if they provide heat to some other part of the house or flat.

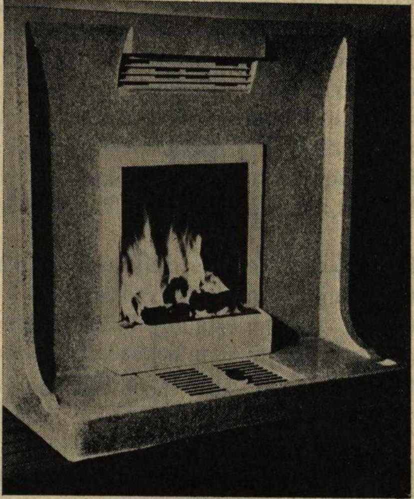
ROOM HEATING APPLIANCES

Open fires. The open fire is used in practically every house in this country. A high proportion of the useful heat is transmitted in the

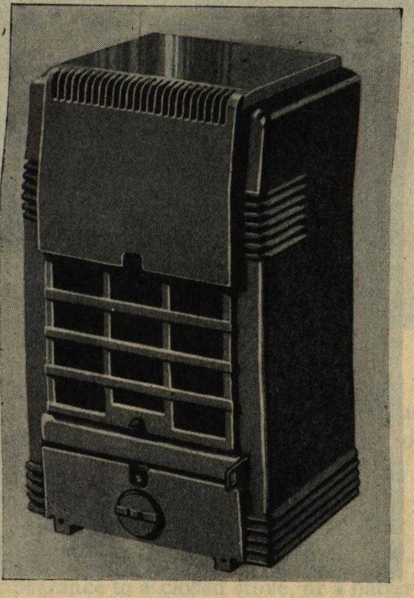
form of radiation. By sloping the firebrick back wall, removal of the heat from the chimney gases is facilitated.

All types of solid fuel can be burnt on the open fire, but anthracite or low temperature coke, i.e. a type of semi-coke with up to 10 per cent volatile content, will burn without smoke. The heat emission being in radiant form, the efficiency is low; under ideal conditions not more than $\frac{1}{5}$ to $\frac{1}{3}$ of the heat in the fuel reaches the room or its occupants. Initial costs are moderate, but running costs are high. The fire needs more attention than any other source of heat.

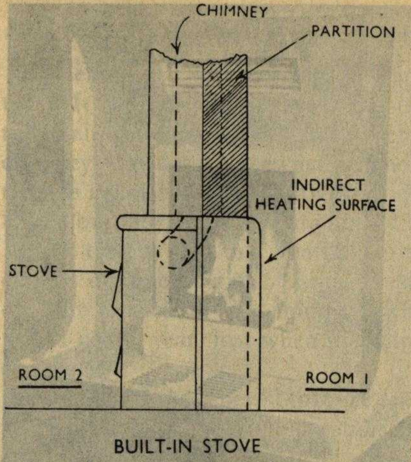
Stoves. On the Continent the stove is as universal as the open fire is here. Stoves vary widely in design and function. Iron stoves with firebrick linings burn any type of solid fuel, and they are suitable for supplying intermittent as well as continuous heating: tiled stoves with and without flues are most suitable for continuous heating on account of their heat-storing capacity; built-in types can be distinguished from free-standing ones. The heat emission is primarily convective, but the large surfaces also emit a fair amount of low temperature radiant heat; with the stove doors open, high temperature heat is radiated. The body of the stove, forming the fuel magazine, combustion chamber and flues, may stand direct on the floor or be supported on legs. Doors and



192. Improved continuous burning open fire with underfloor air control, supplying heat by convected warm air as well as by radiation.



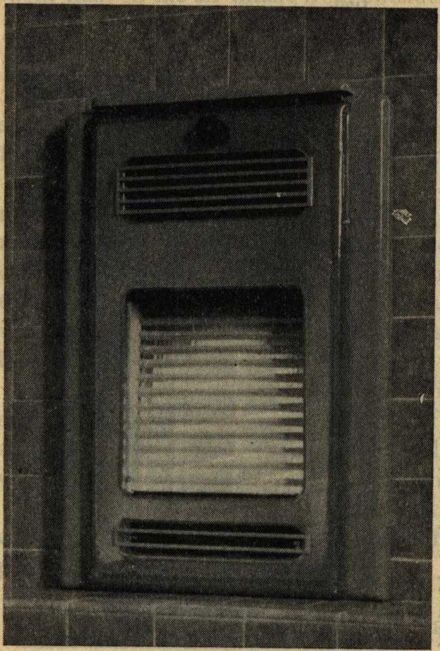
193. "Otto" stove.



194. Section showing stove built into partition in order to heat two rooms.

dampers allow control of combustion air; by operating these, combustion velocity and chimney draught are regulated. The connection between the vertical flue and the stove has to be kept airtight to maintain a draught. The efficiency of the more elaborate types of stove is high; approximately 50–60 per cent of the heat contained in the fuel is useful heat. Although higher than of open fireplaces the initial costs of stoves are low; the difference in price is easily compensated for by the low running costs. With stove firing, less fuel is needed to provide the same amount of heat; service, however, is nearly as laborious as with open fires, and fuel and ash handling cause dust and dirt inside the room.

Gas fires. These can be designed to emit either radiant or convective heat. The former are found more frequently in this country than abroad; the refractory radiants are heated to red or white heat, at the same time forming flue bridges to the chimney. Reflector type gas heaters are also on the market; the highly polished surface reflects the heat into the room. Convective type gas heaters are somewhat similar to ordinary radiators except that instead of steam or water, hot combustion gases pass through the columns.



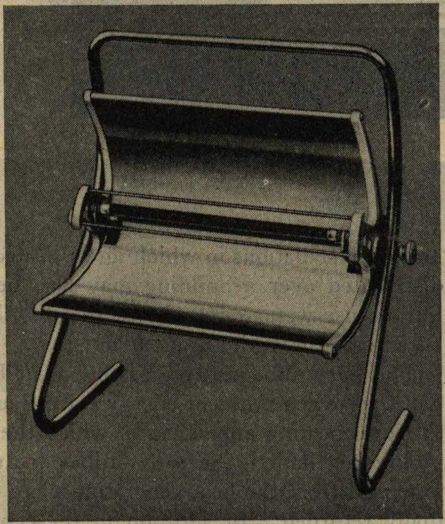
195. Luminous convector gas fire.

The combustion efficiency of gas fires is high, the initial costs are favourable, but

running costs are normally high except in those parts of the country where cheap waste gases from furnace coke production are available. No handling of fuel is necessary, no smoke is formed during combustion, the chimney can be kept smaller than for solid fuel appliances. No chimney draught is required, but flues are made of non-porous materials to avoid seepage of humidity to the outer wall surfaces ; draught breakers are arranged to avoid interference by wind. Gas heaters are compact and save room space, and gas-fired installations do not need space for fuel storage.

Flueless gas fires will be available in the near future. These can be used without detriment to occupants, where sufficient room ventilation is provided, but the gas must be free from sulphuric acid content. These appliances will give up to 60 per cent of theoretical maximum efficiency, whereas gas stoves with flues make use only of 30 to 40 per cent of the heat energy contained in the raw coal.

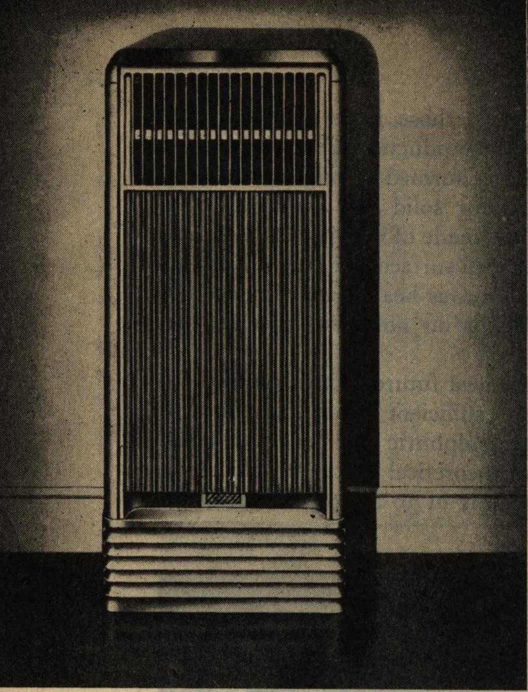
Electric fires.—The majority of electric fires in use consist of a high resistance coil fixed on an insulating body, in some cases combined with a reflector. The heat is given off by radiation and convection. Electric tubular heaters work on the principle of convected heat distribution. They consist of closed tubes containing an electric resistance which is thus protected against damage and safeguards the user against electric shock and high temperatures ; the tubular surface is kept at a relatively low temperature. The initial cost of electric heaters is comparatively low, but the running costs are high. Only about 20 per cent. or less of the available heat content of the coal burnt for the generation of the electricity is utilised profitably for room heating.



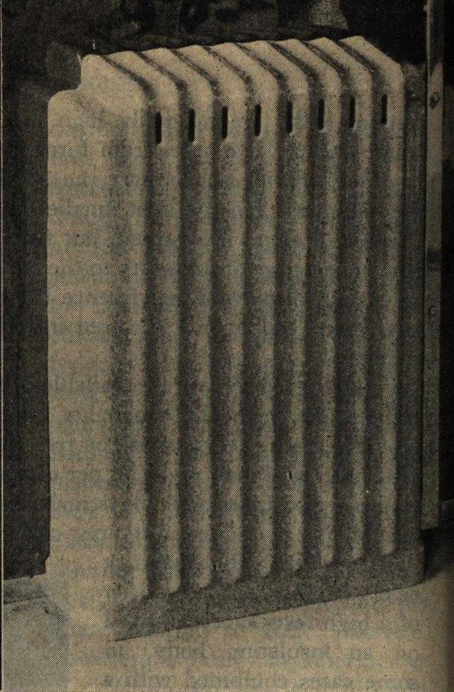
196. Portable electric reflector heater.

HOUSE HEATING APPLIANCES

Central heating installations by definition have a central firing plant—be it one small boiler similar in appearance to a closed stove, or a battery of large boilers similar to those in electrical generating stations. Air



197. Convector type gas room heater.



198. Convector type electric room heater.

heating installations in which air is heated by the combustion furnace and distributed over a building may also be counted under this title. The former use water or steam as the distributing medium, whereas in the latter case air is the heat carrier.

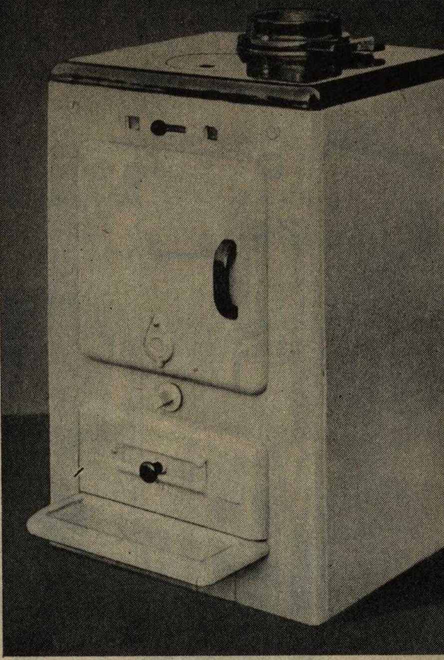
The parts of a central heating installation are: the heat generating plant, in which inherent energy is freed and transmitted to a heat carrier; the local heating appliances at which the carrier releases its energy; the piping installation, the path—tubes or ducts—through which the carrier is passed from the heat generating plant to the local appliance and eventually returned. In addition to these principal components, numerous accessories for control, safety, isolation, measuring and metering are to be found in a heating installation. For economic working and to avoid undue interference it is vital to insulate all those parts of an installation which, being at high temperatures, would otherwise wastefully dissipate heat.

The majority of insulating, or *lagging*, materials owe their properties to internal air cells which reduce the conduction of heat. Materials commonly used include hydrated carbonate of magnesia, diatomaceous earth, minerals of the asbestos group, glass silk, slag wool, hair felt, cork and cellular concrete. These often require an outer covering or binding, in the form of wire netting, felting, canvas or cement compositions.

Apart from the hypocaust heating of the Romans, steam heating is the oldest form of central heating, yet it dates from less than 200 years ago. Any type of steam boiler can be used, but in the majority of installations cast-iron sectional boilers are used, although shell, smoke tube or water tube boilers will be found. Cast-iron is the most suitable material for the boilers, but its application is limited to low pressure systems.*

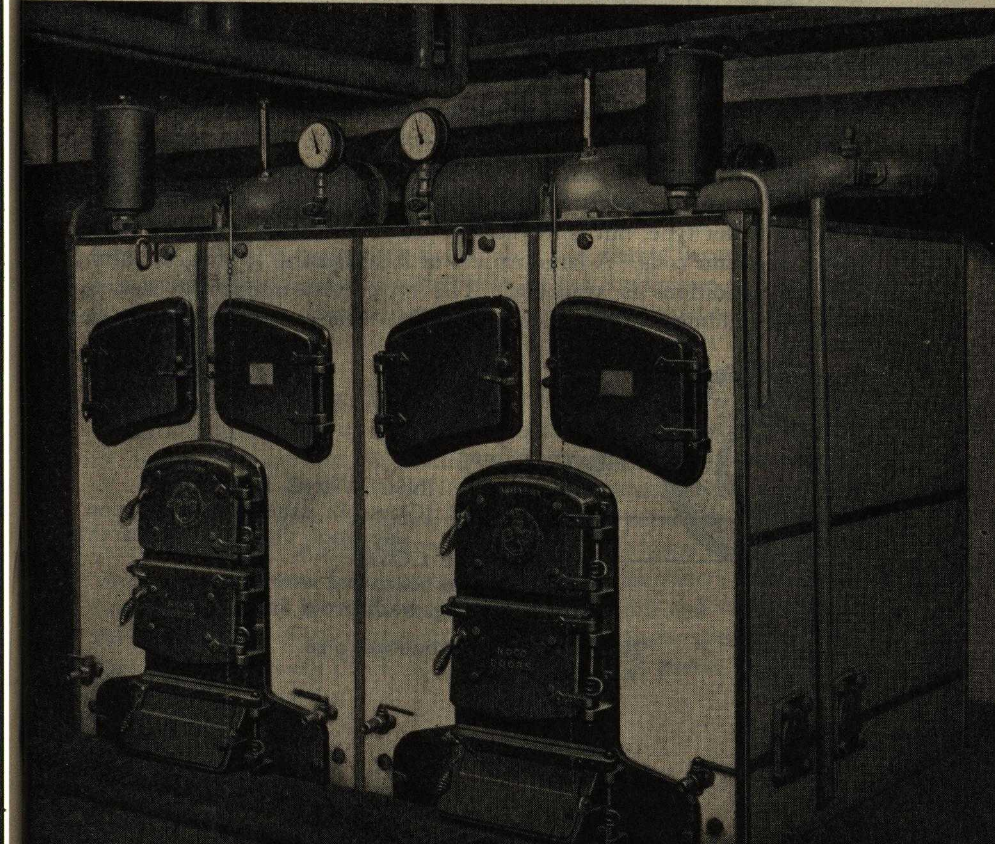
Prime energy used can be any type of solid, liquid or gaseous fuel, burnt

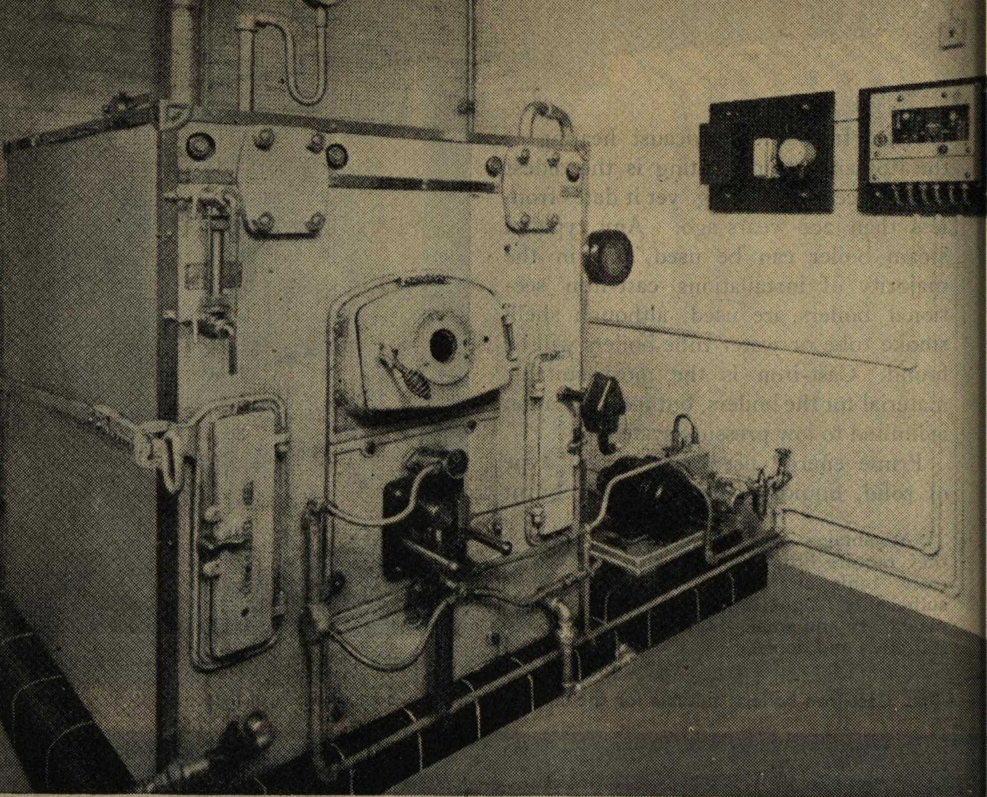
*Advantages of cast-iron boilers are that they require little space and that they can be easily built up on site, each part being sufficiently light for transport without machinery and small enough to pass through staircases and doors.



199. Independent hot-water boiler.

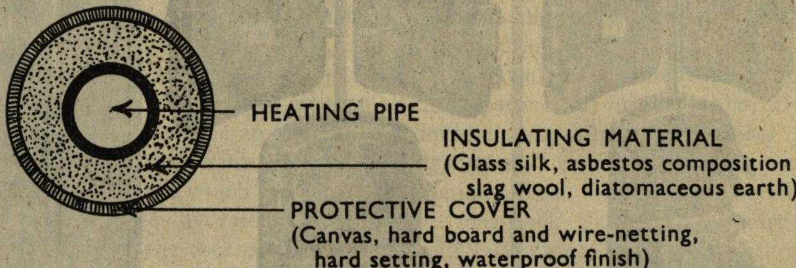
200. Cast-iron boilers, suitable for the central heating of a small block of flats.



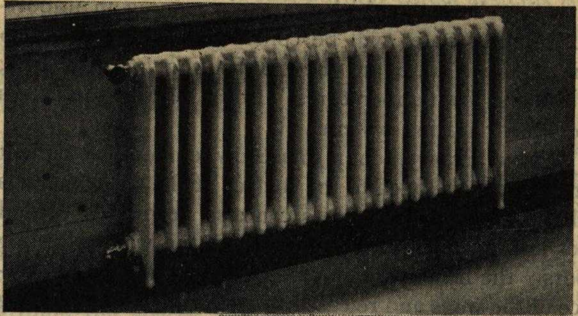


201. Fully automatic oil-burning boiler plant.

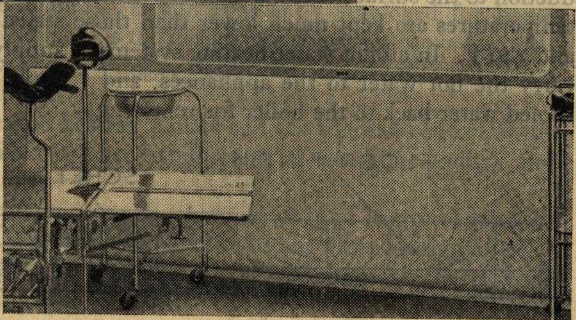
in a suitable furnace or burner. Electricity and even steam can also be employed ; for the last two the generating apparatus will not be of the ordinary boiler type, but is in the form of a cylindrical vessel with electrodes or steam coils. A large variety of local heating appliances suiting any site conditions is available. The type most frequently used for domestic buildings is the radiator, a cast-iron heat emitter, which releases



202. Section through insulated pipe.



203. Cast-iron hospital type radiator.



204. Plain steel radiant panel, as used in an operating theatre.

the heat to the surrounding air mainly by convection. Instead of radiators plain or gilled tubes or other special surfaces can be used ; cast-iron, steel, copper castings and many other materials are utilised to form the heating surfaces.

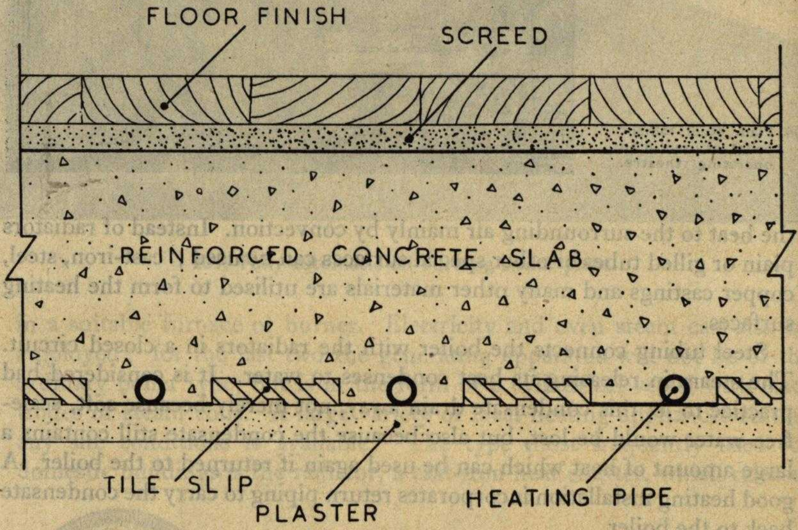
Steel tubing connects the boiler with the radiators in a closed circuit. The steam in releasing its heat condenses to water. It is considered bad practice to let this condensate drain away, not merely because soft, scale-free water would be lost, but also because the condensate still contains a large amount of heat which can be used again if returned to the boiler. A good heating installation incorporates return piping to carry the condensate back to the boiler.

Of the steam accessories only the steam trap need be mentioned. Its function is to separate steam from condensate, thus prohibiting the escape of unutilised steam from the heating apparatus, at the same time preventing the formation of water pockets which would obstruct the flow.

Hot water heating—first used just over 100 years ago—is similar in principle to steam heating. In this case it is not the latent heat of vaporised water (i.e. the excess heat necessary to vaporise the water) which is used, but the heat given up by the liquid between the flow and return temperatures. In the case of low temperature hot water heating systems the temperature drop is from say 180°F. to say 150°F. In high pressure hot water or

superheated hot water installations, which are again gaining in importance, the temperature of the water will be considerably higher, up to 300°F. or even more. These latter are the distributing temperatures; local radiators are worked at low temperatures. Local heating appliances are similar to those of steam heating systems.

An ingenious and pleasant arrangement is to use low temperature radiant panels. Cast-iron or steel panels, fixed to the surface of the walls, ceilings or floors take the place of radiators; panels can also be hidden behind finished wall surfaces and pipes can be embedded in the wall or ceiling plaster, or in the floors; the heat of the apparatus is transmitted by conduction to the surface of the walls and released by radiation. The working temperatures are kept much lower than those stated above, between 90° and 140°F. In all hot water heating systems, " supply " or " flow " pipes carry the hot water to the appliances, and " return " pipes convey the cooled water back to the boiler for reheating.



205. Section through reinforced concrete floor slab, showing radiant ceiling heating pipe installation.

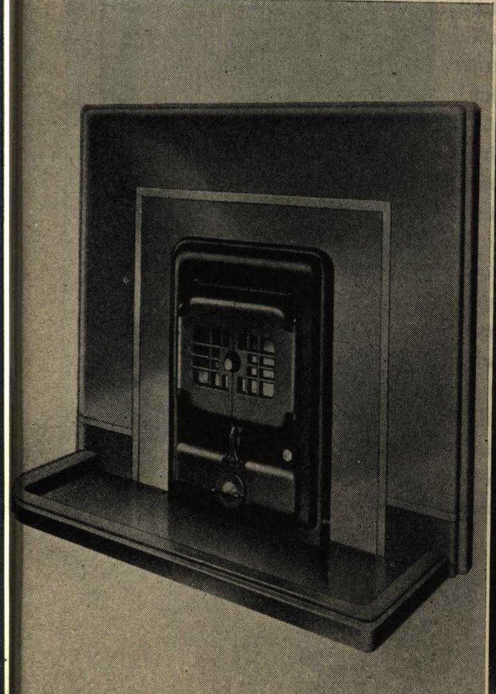
Two methods of heating by hot water should be distinguished; these are the gravity system which works without any form of mechanical accelerator, depending for its circulation on the difference of weight between the flow and the return water, and the accelerated hot water system. In the latter installation the water inside the system is propelled mechanically by an accelerator or pump, which is usually driven by an electric motor.

With air heating the energy is either directly applied for heating the air or is first distributed in the form of steam or hot water to fan chambers.

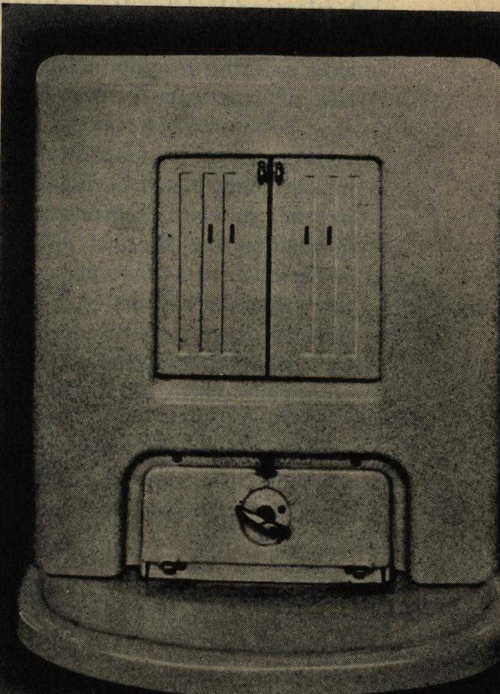
The firing equipment of fuel burning direct systems is similar to, though larger than, that of a stove ; the equipment used in the indirect system is similar to that of a normal steam or hot water system. With electricity as the source of energy wire coils form the heating battery. No local appliances comparable with radiators or similar equipment are used, the heated air being discharged through grilles or louvres into the space to be heated. Room air can be returned to the boiler or heating battery. The carrier "air" is directly used as heat donor. It is conveyed from the central source through ducts to the point to be heated. In systems utilising return air, circulation can be by gravity based on the buoyancy of the hotter air, or by means of electrically driven fans. Air heating is mainly used for warming big spaces but abroad is also frequently employed for house heating. A recent development is the design of a combined stove for heating and hot water service which makes use of the heat of the combustion gases from the water heater.

The operation of central heating boilers and the thermal control of the combustion are simplified by the introduction of magazine boilers and automatic stokers.

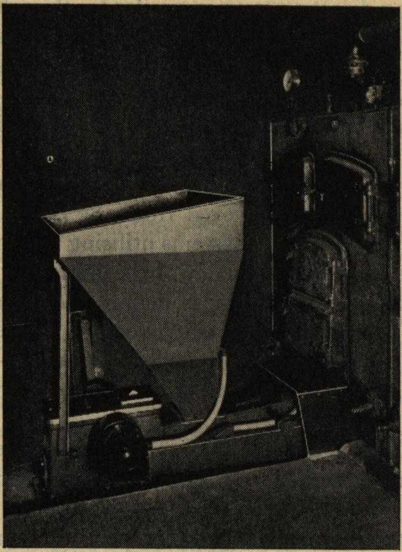
Thermostatic control from room thermostats and compensators or weatherstats to govern the water temperature in hot water heating installations reduce the responsibility of the stoker and increase the thermal efficiency of the plant.



206. Siesta No. 2 Inset stove, with back boiler for domestic hot water supply, as installed in the Ministry of Works temporary houses.

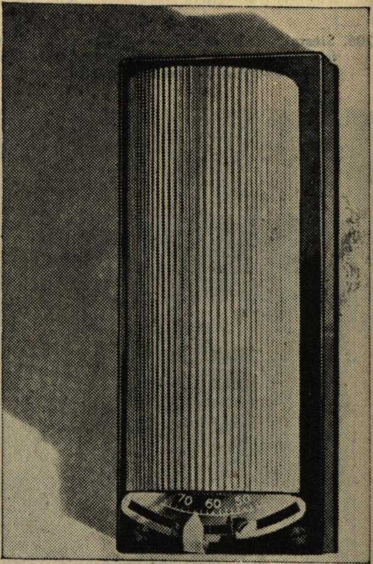


207. Inset type open-close stove with sliding doors.



208. Small automatic stoker.

If the expenditure on chimneys, trimming of floors, etc., is taken into account, installation costs for central heating plants are hardly higher than those for open fireplaces. Owing to higher thermal efficiency, the running costs are definitely lower than with open fires, particularly if the heating installation is serviced by the user as with individual house heating installations ; the attendance costs vary in accordance with firing methods and extent of service, but will hardly outweigh the saving over open fires in respect of fuel. For a small household the running costs of central heating plants may appear expensive in comparison with the cost of keeping in one or two fires. This is hardly a fair comparison. The former provides conditions of comfort throughout the house, while the other gives local warmth only. It is also true that more skill is required to look after a central heating installation ; lack of experience in this respect can be the cause of excessive working costs. Taking all factors into account, it will be found that in the standard central heating installation the thermal efficiency is between 36 and 50 per cent, or more than double that of the open fire. In large installations worked by specially trained personnel, equipped with automatic firing equipment and with suitable control apparatus, the thermal efficiency can easily be increased by 10 to 20 per cent. Under these



209. Room thermostat.

conditions, in spite of slightly higher service and maintenance costs, central heating is appreciably cheaper than open fires. The adoption of thermostatic control will not only increase the absolute efficiency by helping to avoid wastage of heat, but also increases comfort by eliminating overheating in warmer weather and, on cold days, obviates falls in the temperatures during non-service hours.

ELECTRIC THERMAL STORAGE HEATING

This form of water heating is a modification of central heating with an electrode boiler instead of a fuel-fed boiler, which takes advantage of electricity generated during night hours and sold at a preferential rate. Water is heated in cylinders during the night and used the next day. Although the initial costs of such a system are high, low running costs compensate for them. The total thermal efficiency is inevitably low, and will seldom exceed the 15 per cent mark. On the other hand, the power is generally offered at very favourable rates as, owing to the difficulties of storing electricity, it pays the supply company to charge at a low rate during hours in which there is little normal demand. Even a small return for power supplied at night helps to cover overhead costs.

Electric thermal storage has the advantage of completely eliminating smoke; service costs are also low. Its application is limited by the generating capacity of the supply station and by the hours made available for supply.

DISTRICT HEATING

Itiis a small step from the central heating of individual houses to the heating of blocks of houses from one central boiler house. These latter heating installations are known variously as District Heating, Town Heating and Community Heating. This system differs from standard forms of central heating in two main respects, economic and technical.

The first difference is that the heat is not generated by the owner or tenant of the premises to be heated, but by an enterprise which sells heat on a commercial basis, as undertakings generate and sell gas or electricity. The undertaking can be a private one working for profit, a public utility run by the local authority, or a co-operative undertaking belonging to and worked on behalf of the occupants of the various premises supplied.

Technically the new features are the long-distance underground distribution and the metering of the heat distributed to each consumer.

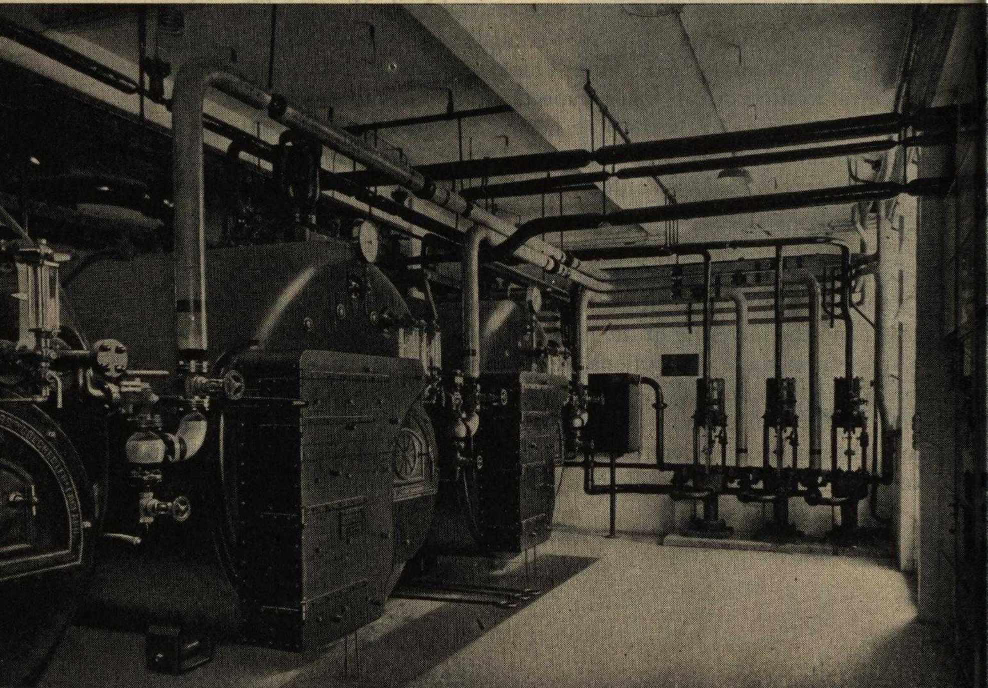
Apart from these distinctions, there appears to be little difference between standard central heating and district heating, from the viewpoint of the consumer. In design, the central boiler house plant—in most cases an independent plant—is similar to any domestic boiler house, except for its larger size. Boilers are normally rather like those used in

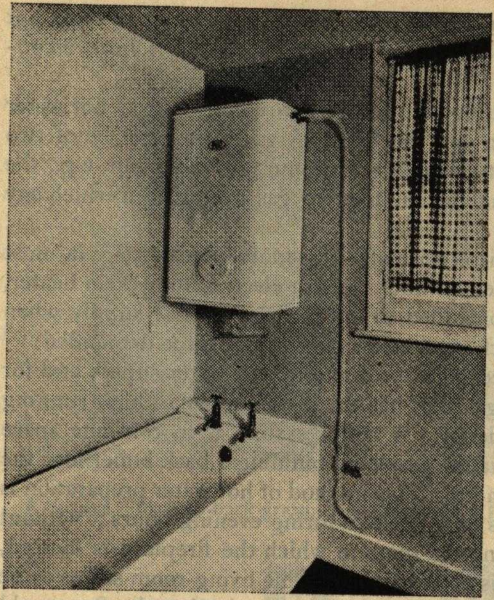
power plants, though smaller groups, e.g. housing estates, may use cast-iron boilers.

District heating has many advantages. First, it eliminates smoke at each house and greatly reduces it in the district as a whole, as only one boiler plant is required. This can be worked and supervised by a specially trained staff, and can be equipped with instruments and automatic apparatus for continuous control of function and efficiency. Secondly, fuel consumption is minimised on account of this control; very high efficiency can be achieved, in spite of the heat losses inevitable in long-distance distribution. Running costs are low on account of high efficiency and bulk fuel supply ; even though overhead costs must be charged to the consumer, the heat can be supplied at a very reasonable price. Living space is freed in every house which needs no boiler-room, fuel store or chimneys. As the service can be continuously in operation, heat is immediately available at any time, and no preparatory lighting or kindling is required as with open fires or individual central heating. In addition to a clean atmosphere, the houses themselves are kept clean, as there is no dust or dirt from fuel and ashes. The occupant saves all time and labour normally spent on looking after the heating ; all that he has to do is to turn on a valve, as he now turns on the cold tap, the gas cock or the electric light switch. There is no risk of fire, escaping gas or short circuit.

Water at low or high pressure appears to be the most suitable heating

210. Treble-pass shell-type steel boiler, suitable for local district heating.

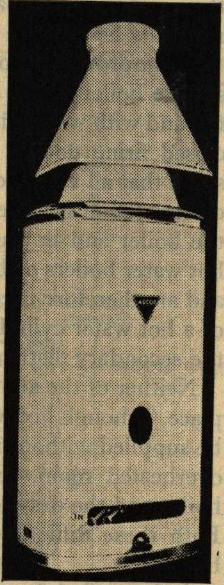




211. Electric storage water heater.

medium, because apart from ease of distribution in any type of development, it requires no traps, thus avoiding continuous slight losses and frequent inspection and maintenance of the long-distance mains; the self-equalising capacity of the water and the adjustment of the water temperatures to outdoor temperatures help to increase the thermal efficiency of the system and to reduce the loss of heat in distribution. Hot water as a medium is also best adapted for providing a domestic hot water supply.

The initial costs for the local installation are less than for any other type of central heating, owing to the absence of the boiler. The prime costs for the distributing and generating plant would be charged as part of the running cost. Total running costs would be slightly in excess of those for individual central heating installations, owing to the payment for service and maintenance. From 40 to over 50 per cent of the heat contents of the coal needed reaches the consumer.



212. Gas water heater.

DOMESTIC HOT WATER SERVICE

A domestic hot water supply is a necessity in a modern house. Without it a high standard of cleanliness is well-nigh impossible.

Small quantities of water can be heated on cooking appliances. The kettle on the gas ring or on the kitchen range may provide hot water for

cleaning dishes, hand washing or shaving water, but cannot provide hot water for the bath and the washing. Such a procedure is both inconvenient and uneconomic.

Gas and electric water heating are useful in providing a direct hot water supply to the sink, the basin and the bath. A gas heater can be of two types: the pressureless heater which serves one hot water tap, e.g., the bath or the kitchen sink, and the multi-point gas heater from which any number of taps can be fed.

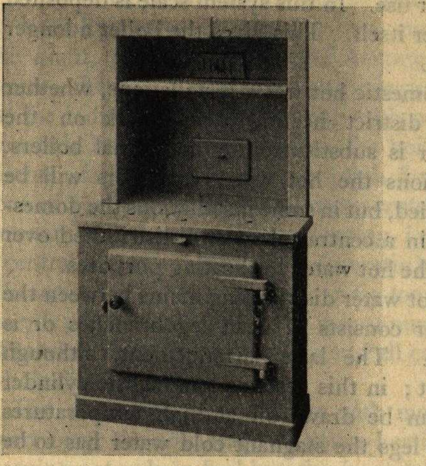
Electric heating equipment is normally of a multi-point type; in most cases it consists of a hot water cylinder with an electric immersion heater, which is thermostatically controlled to cut out the electric supply when the water is hot and to switch it on again as soon as heat is demanded.

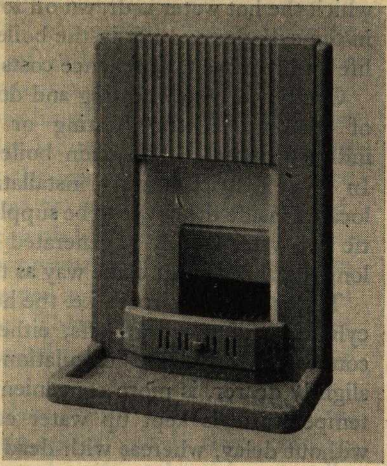
A range which can be used both for domestic hot water supply and for cooking has certain advantages, but has the disadvantage of high running costs and low thermal efficiency. A better system is to combine space heating with domestic hot water service by building a back boiler into the combustion flues of the open fire. This method of hot water preparation is adequate where hot water is only needed during evening hours; without forcing the fire or overheating the room in which the fireplace is located, the generation of hot water is not expensive. The living-room seems to be the most suitable place for fixing the back boiler, in that the fire would normally be lit there more often than in any other room.

An improvement on this system is the adoption of a domestic hot water service boiler of the open type, which heats the room as well as an open fire and with which the supply of hot water can be boosted by working with closed firing doors. This type of installation is generally direct, in the sense that all water to be heated has to pass through the boiler itself. The direct system has the disadvantage that scale formation takes place inside the boiler and in due course the waterways get choked up. Domestic hot water boilers or back boilers are not suitable for instantaneous heating and are therefore used in conjunction with storage equipment, in the form of a hot water cylinder or a closed storage tank. From this storage vessel the secondary distributing mains are taken to the draw-off points.

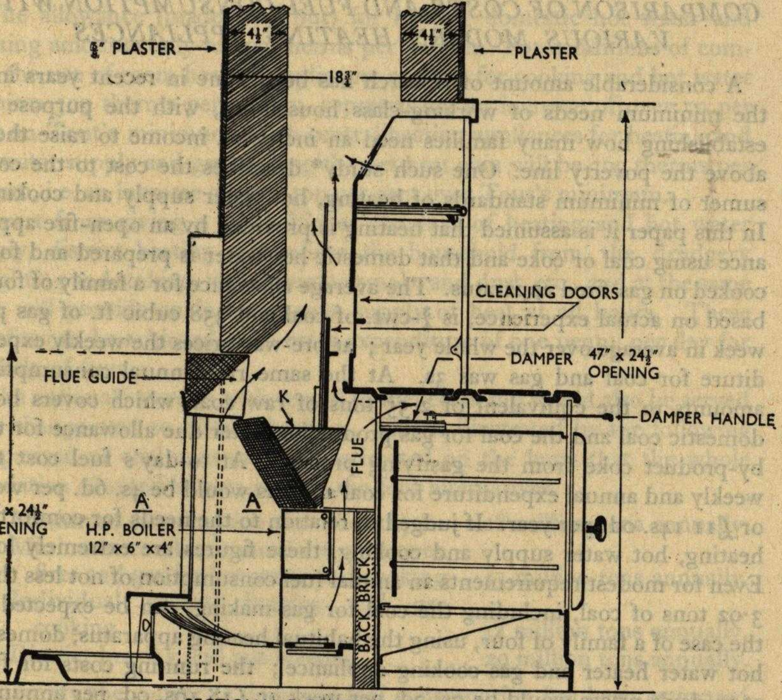
Neither of the above two solutions can be fully satisfactory. In the first place, although hot water is required even in the hottest weather, it cannot be supplied without increasing the temperature in what may already be an overheated room. Secondly the need for short pipe-runs between the boiler and the draw-off points may severely limit the freedom of the plan. Both these difficulties are clearly exposed in the design for the Portal house.

A domestic hot water system is called indirect where the water heated in the boiler is not itself used but is continuously circulated between the boiler and the cylinder, in which a coil serves as a heat exchanger; the primary circuit is closed and kept apart from the secondary circuit, from





A "Janus" back to back grate. 213. Oven. 214. Fireplace. 215. Sectional elevation.



SECTIONAL ELEVATION THROUGH FIRE AND OVEN

which the hot water is drawn off for use. In this system scale is deposited in the cylinder and not in the boiler itself. This gives the boiler a longer life and reduces maintenance costs.

Combined house-heating and domestic hot water installations, whether of standard central heating or district heating type, work on the indirect system. The main boiler is substituted for individual boilers. In most district heating installations the hot water calorifiers will be located inside the house to be supplied, but in some installations the domestic hot water supply is generated in a central plant and distributed over long distances in the same way as the hot water for heating purposes.

The secondary circuit, i.e. the hot water distributing mains between the cylinder and the draw-offs, either consists of dead leg branches or is connected for closed circulation. The latter arrangement, although slightly dearer, is more convenient; in this case, as long as the cylinder temperature is kept up water can be drawn-off at high temperatures without delay, whereas with dead legs the stagnant cold water has to be run to waste.

COMPARISON OF COSTS AND FUEL CONSUMPTION WITH VARIOUS MODERN HEATING APPLIANCES

A considerable amount of research has been done in recent years into the minimum needs of working-class households, with the purpose of establishing how many families need an increased income to raise them above the poverty line. One such study* describes the cost to the consumer of minimum standards of heating, hot water supply and cooking. In this paper it is assumed that heating is provided by an open-fire appliance using coal or coke and that domestic hot water is prepared and food cooked on gas-fired apparatus. The average allowance for a family of four, based on actual experience, is ¾-cwt. of coal and 358 cubic ft. of gas per week in average over the whole year; at pre-war prices the weekly expenditure for coal and gas was 3s. At the same rate annual consumption amounts to the equivalent of 2·55 tons of raw coal, which covers both domestic coal and the coal for gas production, after due allowance for the by-product coke from the gasifying process. At to-day's fuel cost the weekly and annual expenditure for coal and gas would be 4s. 6d. per week or £11 14s. od. per year. If judged in relation to the needs for comfort in heating, hot water supply and cooking, these figures are extremely low. Even for modest requirements an annual fuel consumption of not less than 3·92 tons of coal, including the coal for gas-making, can be expected in the case of a family of four, using the habitual heating apparatus, domestic hot water heater and gas-cooking appliance; the running costs for fuel at to-day's prices would be 7s. 3d. per week or £18 16s. od. per annum.

* *The Standard of Living in Bristol*, by Herbert Tout, C.M.G.,M.A.

With a modern system of central heating—allowing for the living-room to be fully heated during day time and "background heated" during the night, and for background heating of bedrooms over the full 24 hours—the fuel consumption and running costs will work out as follows: (a) for individual central heating with combined service for heating and domestic hot water preparation, the boiler located in the living-room or kitchen, including coal consumption for the gas used in cooking: 2·92 tons of coal per annum at running costs of 6s. per week or £15 12s. od. per annum; (b) for district heating, i.e. with heat supply on tap from a central plant for heating and domestic hot water supply and including an allowance for cooking by gas: 2·65 tons per annum at running costs of 6s. 7d. per week or £17 1s. 6d. per annum. These figures include the cost of service, maintenance, repairs and all capital and interest charges for the whole district heating plant.

The above figures show that with modern central heating appliances, apart from the advantage of house heating against purely room heating, a saving not only in fuel but also in costs can be achieved; time normally spent in fuel carrying, removing ashes and making fires is saved, while the house is better heated.

The allowance (made by Tout) for heating domestic hot water and cooking amounts only to 197 therms per annum. For conditions of comfort the use of room heating appliances and gas for cooking and hot water requires 309 therms per annum, representing an increase of over 50 per cent on Tout's minimum. With central heating appliances for heating and hot water supply and gas cooking the net heat gain will be 399 therms per annum, i.e. an increase of over 100 per cent over Tout's minimum.

Apart from giving a much higher standard of heating and hot water supply, district heating will relieve the household from the drudgery of lighting and stoking, will eliminate smoke and dust, etc., and at the same time will provide an instantaneous supply of heat at all hours. These benefits can be achieved at an extra expenditure of one penny per day for a family of four.

The national interests with regard to fuel economy would also be served by a change-over to district heating. This is illustrated by the following comparison of coal consumption, estimated on the basis that the whole population adopted in turn each of the four alternatives.

(1) Minimum consumption (insufficient) .. 28 million tons annually.
(2) Minimum comfort conditions with open fires and gas for hot water and cooking .. 43 million tons annually.
(3) Individual central heating and gas cooking .. .. 32 million tons annually.
(4) District heating and gas cooking .. .. 29 million tons annually.

In reality the country's domestic fuel consumption has been estimated as between 53 and 63 million tons per annum, that is to say 25 to 50 per

EFFICIENCIES AND COSTS OF VARIOUS HEATING APPLIANCES

Item	Thermal Efficiencies	Ordinary Open Fires	Improved Open Fires	Stove	Gas Fires	Chimney-less Gas Fires	Electric Fires	Electric Thermal Storage Heating	District Heating	Central Heating (Block of Flats)	Heating of Housing Estates: Local District Heating	Heating of Housing Estates: Individual Central Heating
1	Efficiency of Utilisation (Heating-up, Cooling-down, Banking)	95%	95%	95%	97%	97%	97%	94%	90%	85%	95%	90%
2	Efficiency of Room Appliance	20%	30%	50%	60%	90%	100%	99%	99%	99%	99%	99%
3	Efficiency of Internal House Distribution	—	—	—	—	—	—	88%	88%	80%	95%	95%
4	Efficiency of Local Storage	—	—	—	—	—	—	95%	98%	—	—	—
5	Efficiency of External Long Distance Distribution	—	—	—	—	—	95%	95%	89%	—	80%	—
6	Efficiency of Boiler or Heat Energy Generating Plant ..	—	—	—	64%*	64%*	27%	27%	75%	70%	73%	55%

7	Thermal Efficiency of Total Heating Process	19%	28.5%	47.5%	37%	55.5%	25%	20%	51%	47%	52.5%	47.5%
8	Costs of Heat : Efficiency Relative to Fuel or Energy Purchased	19%	28.5%	47.5%	58%	87%	97%	78%	51%	47%	52.5%	47.5%
	derived from Items	1, 2	1, 2	1, 2	1, 2	1, 2	1, 2	1 to 4	1 to 7	1 to 7	1 to 7	1 to 7
9	Fuel Purchased Price per Unit .. Price per Gross Therm	Best 70/- 3d.	House 70/- 3d.	Coal 70/- 3d.	Gas 1/- 12d.	Gas 1/- 12d.	Electy. $\frac{3}{4}$d. 22d.	Electy. $\frac{1}{2}$d. 14.6d.	Coal(Blk) 40/- 1.72d.	Coke or Coal 60/- 2.57d.	Coal (Bulk) 50/- 2.15d.	Anth'cite 90/- 3.8d.
10	Price per Net Therm	15.8d.	10.5d.	6.3d.	20.5d.	13.8d.	22.6d.	18.7d.	3.4d.	5.5d.	4.1d.	8.0d.
11	Service and Maintenance per Therm (including Capital and Redemption Charges for District and Community Heating)	—	—	—	—	—	—	—	4.4d.	2.5d.	5.8d.	1.0d.
12	Total Cost per Net Therm	15.8d.	10.5d.	6.3d.	20.5d.	13.8d.	22.6d.	18.7d.	7.8d.†	8.0d.	9.9d.‡	9.0d.

* Efficiency allows for By-Products, Chemicals and Coke at their Net Calorific Values.
† Therm at Meter 6d.
‡ Therm at Meter 8.8d.

cent. higher than the figure for comfort conditions with open fires, etc. Assuming district heating conditions as a yardstick for the future consumption with an additional margin of 25 to 50 per cent, the savings in fuel per annum would be 17 to 20 million tons of coal. In consequence 55,000 to 65,000 miners could be freed from the pits. A summary of fuel economy and unit costs for various forms of heating appliances is given on pages 290-291. This shows that district heating as a potential promoter of fuel economy should be the aim after the war. The need for economy has not ceased with the end of the war. The interests of future generations demand that we conserve the natural fuel stocks of the country.

As a labour-saving device, district heating will help to solve the problem of domestic service ; to the mother who has to run her own home it will mean more time for her children ; every housewife will gain more leisure for following her chosen cultural interests.

DIFFERENCE BETWEEN THE HEATING OF HOUSES AND OF FLATS

Various distinctions can be made between the heating of flats and of houses ; these may help to influence the choice between the two alternatives.

(1) *Demand.*—As the average cubic capacity of flats is less for the same number of inhabitants than that of houses, the gross heat demand of the individual flat is likely to be smaller than for houses. At the same time the relative demand, i.e. for each cubic foot, will also be lower for flats, as each flat has fewer surfaces exposed to the outer atmosphere, being more often surrounded by other dwelling units. On average the thickness of the outer walls will also be greater for structural reasons ; this also reduces heat losses, other things being equal.

(2) *Occupancy.*—Flat occupiers tend to demand heat for fewer hours, not only owing to the smaller specific heat losses, but also on account of their different living conditions ; apart from elderly, non-occupied persons, flat-dwellers less often require heat during daytime as they will generally be away at work. In the evening demand will rise to a peak.

(3) *Fuel and ash transport.*—These two items can create a problem on the upper floors of blocks of flats where local solid fuel appliances are used, as a method of conveyance to and from the basement will be required. This gives the advantage to central heating, gas or electric heating, for none of which transport is necessary. Individual central heating (storey heating) is as inconvenient as the use of solid fuel appliances. Despite its disadvantages, however, this system was given preference in some continental towns, to spare the landlord from responsibility for heating. To help

solve the practical difficulties, specially constructed combined coal and ash lifts are provided.

(4) *Storage.*—This problem is closely related to the previous one. Solid fuel appliances in multi-storey buildings usually require two types of fuel storage accommodation, the bulk winter supply store in the cellar and the working fuel store in the flat; the latter can be omitted and the daily demand kept in buckets if daily haulage from the cellar store can be arranged.

(5) *Living space.*—The small size of the modern flat requires that all ancillary equipment should be kept down to a minimum. A radiator arranged below the window saves floor space and eliminates danger to furniture from burning fuel or red hot surfaces. Useful space is gained on walls and in the corner of the room.

(6) *Chimneys.*—Solid fuel heating devices in multi-storey buildings require a chimney for each heating appliance, thus sterilising much useful space. The proportions of a room are improved by the omission of chimney breasts. Compared with two-storey buildings, the cleaning of the chimneys in blocks of flats is more complicated.

(7) *Distribution of heat.*—With the increase of height and size of a building the incidental heat losses in transmission increase.

(8) *Heat density.*—The density of heat demand is greater per unit of ground area in flat development than for single, semi-detached or terrace houses. This has an important bearing on the possibility of adopting district heating. In built-up areas the mains for heating have to be laid, together with pipes and cables of other services, under roadways. In open areas it will be easier to accommodate the pipelines, the construction of the conduits can be kept lighter as the absence of heavy traffic reduces the need for special reinforcement.

THE POST-WAR RECONSTRUCTION PERIOD IS AN OPPORTUNE MOMENT FOR CHANGING OVER TO MODERN METHODS OF CENTRAL HEATING

The various advantages of central heating have been outlined above. Actual results, based on practical experience, are available not only from upper-class houses, blocks of flats and hotels, but also from factories, offices and hostels. The public are conversant with central heating and appreciate its benefits, even though their experience of it has not extended to their own homes.

To achieve the full advantage, not merely from the economic but also from the technical aspect, it will be necessary to make central heating part of the initial equipment of post-war homes.

District heating is less well known here than abroad; however, some very useful pioneer work can be found in this country. Apart from the

installation in many recent factories and institutions of central boiler plants with long distance distribution, there is an installation in Manchester dating from 1911, and two estate heating schemes at Dundee which were built shortly after the last war. Other examples are to be found on various trading estates. All these plants appear to work efficiently and to give satisfaction.

In the congested areas of cities the problem of laying pipes in roadways is complicated by the fact that so much space is already occupied by gas, water and sewage mains and electric and telephone cables. Destruction through bombing has necessitated many changes in these services, and when the roads are opened for permanent repair the new equipment for heating purposes can be laid. This opportunity may never occur again.

HEAT AND POWER GENERATION

It is an incontrovertible fact that the generation of electricity operates at a low efficiency; even the best equipped and most modern power plants can utilise little more than 30 per cent. of the energy contained in the coal. This closely approaches the theoretical maximum efficiency obtainable in steam power generation, which is limited through the operation of the second law of thermodynamics. In the last three decades extraordinary strides were made towards this theoretical maximum, as the following figures show. In 1900 the generation of 1 kwh electrical power required 6 lbs. of coal whereas in 1910 4 lbs. had to be burned, in 1920 2·2 lbs. of coal were needed and in 1940 1·1 lbs. of coal produced the same quantity of electrical energy.

The first district heating scheme took advantage of the fact that large quantites of waste steam are rejected from the exhaust and back pressure steam engine or turbines; this exhaust steam was used for heating purposes. Lack of coincidence of power demand and heat requirements and the removal of power stations from city centres to the outskirts, or even their establishment in open country, put a halt to developments in this direction; the evolution of condensing type steam engines and of high vacuum turbines, which displaced the earlier generating plants, simultaneously reduced the waste steam available. The introduction of thermal storage equipment overcame the difficulty that the demand for power and heat did not coincide, and the combined production of heat and power on an economic scale was made possible. Heat produced at about 60 per cent efficiency and power at about 30 per cent efficiency in individual plants can be generated at about 68 per cent efficiency in combined heat and power plants; these figures express better than words the advantages of combining heat and power generation, although it must be admitted that certain difficulties of synchronising heat and power generation remain.

IS DISTRICT HEATING A PRACTICAL PROPOSITION?

Doubts as to the practicability of district heating can be answered by reference to experience in U.S.A., Russia and on the Continent. Furthermore, this country—owing to its climate—is a potential user of heating over more days in the year and at the same time suffers less severe minimum temperatures than many other countries. In respect of costs estimates favour its adoption in this country.

The estimate of prime costs for central heating installations is based on the difference between the room temperature required and the lowest outdoor temperature at which the full heating effect has to be achieved (Design Temperature). The greater the temperature difference is, the dearer the handling plant will be. On the other hand the running costs include redemption of capital costs, and therefore depend on the time and the extent to which the heating installation is used ; this relation can best be expressed in degree days. The sum of the daily difference between room temperature (base temperature) and the daily mean outdoor temperature over the heating season gives the "annual degree days." This figure is then divided by the maximum temperature gradient to give the "Degree Day" factor.

The higher the value of this factor the more the heating plant is utilised, with the result that capital costs represent a smaller proportion of the total running costs. This means that expenditure on an elaborate heating plant is more justified in this country than in any other of the towns as shown in the following Table.

DEGREE DAY FACTOR IN VARIOUS CITIES.

	1 Annual Degree Days	2 Design Temper-ature	3 Base Temper-ature	4 Temper-ature Gradient	5 Degree Day Factor
British Isles aver.	4200	30	60	30	140
London . .	3970	32	60	28	141
Bristol . .	3810	32	60	28	136
Berlin . .	6330	5	64	59	107
Vienna . .	5250	5	64	59	89
Moscow . .	9800	—25	60	85	116
Rome. . .	1530	25	60	35	44
Madrid . .	2770	25	60	35	79
New York . .	5350	0	65	65	82
Los Angeles . .	1510	35	65	30	50

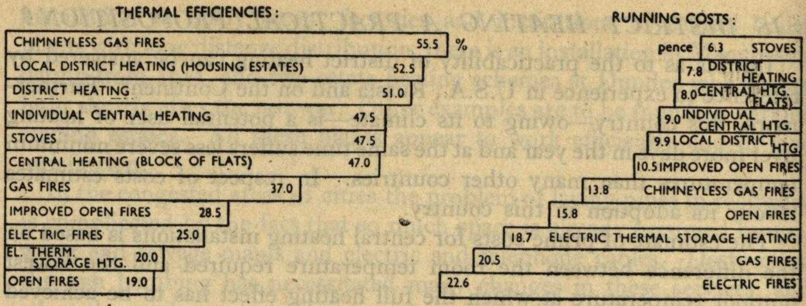


Diagram showing the relative Thermal Efficiencies and Running Costs of various heating appliances.

It can be said that long-distance heat is likely to be not only a paying proposition in densely built-up areas, such as those in which it was originally applied ; it can also be suitably used in lower density development, if the principle of background heating is adopted. It appears vital to introduce the metering of the heat consumed. This not only avoids wastage, but also forms a basis for distributing the cost between individual consumers. There is no reason why metering should be applied to heat less successfully than it is already applied to gas and electricity.

The electric thermal storage system is an important competitor of district heating ; it will, however, be realised that it cannot compete in respect of fuel economy. The extent of electrical thermal storage heating installation is limited by the amount of power generated at the electricity works, whereas the application of district heating is limited only by the heat losses in the distributing mains.

The installation of a district heating system involves considerable capital costs and cannot be lightly undertaken. It is believed, however, that the description given here of its potentialities and of its advantages over any other system will have demonstrated to the reader that it merits serious consideration as the method of the future.

THE HEAT PUMP

A few years ago, at the Technical University in Zurich, a form of heating was installed which, though established theoretically for a century, is so novel in application that it deserves mention in this article.

It is necessary to introduce this heating system—at the moment only in its infancy—by giving a brief theoretical description of its mode of operation.

Matter can exist as a solid, a liquid or a gas, the form depending on the temperature and pressure. Heat has to be supplied to transform solids

into liquids and liquids into gases, and removal of heat energy is needed to alter the state in the reverse direction. Without a supply of heat, ice at 32°F. cannot be changed into water at the same temperature, and water at 212°F. must be charged with more heat to transform it into steam at the same temperature. The heat required to change a solid to its liquid state is called the *latent heat of fusion*, and the heat required to change a liquid to its gaseous state is called the *latent heat of vaporisation*. Latent heat is used to change the state of the material and does not alter its temperature.

Latent heat of vaporisation is used in steam heating systems. It is freed during the process of condensation and utilised for heating. It is also used for purposes of refrigeration ; in this case the cooling liquid draws heat from the refrigeration chamber as it evaporates.

Broadly speaking, there are four main elements in a refrigerator. In the first, the *compressor*, the gas or vapour is compressed. This makes it hot, and in this state it enters the *condenser*. Here, still under pressure, it is brought down again to a lower temperature and the vapour liquefies ; the heat freed is forced to escape. The liquid then passes through the *regulating valve* into a chamber at lower pressure, the *evaporator*, in which the liquid again vaporises. In doing so, it has to extract latent heat of vaporisation from the surrounding air, which in turn it cools.

The " heat pump " is in effect a refrigerator used in reverse. Instead of taking advantage of the evaporation of the liquefied vapour in the evaporator, it uses the heat emitted from the condenser for heating purposes. In order to raise local indoor temperatures, it actually cools down a large amount of outside air (or water), though this cooling is not made use of for refrigeration.

The principal theoretical objection to the method is that the " heat pump " operates least efficiently just when the maximum amount of heat is needed, that is when outside temperatures are at their lowest.

To get the maximum performance from the " heat pump," the condensing temperature has to be kept as low as possible, i.e., well below the temperatures used in most heating plants, but still suitable for embedded panel systems operating between 105°F. and 120°F. At these temperatures it is possible to extract from the condenser between 3.7 and 4.3 times the amount of heat energy applied to operate the compressor. In other words, its thermal performance is about four times that of direct electric heating.

Owing to the low efficiency possible in generating electricity by steam, and to the complexity and expense of the " heat pump," it is not likely that this method of heating will have any general application in England. In Switzerland and in other countries where fuel is scarce and where the bulk of the power is generated hydro-electrically, it is more likely to find favour. Here it might be adopted as a practical means of extracting energy from the hot water at present run to waste from combined heat and power plants attached to factories, and as a by-product of large refrigeration

plants. In both cases it would probably only be used in the immediate vicinity of the plant.

THERMAL INSULATION OF BUILDINGS

When designing the heating system for a new house, it is not reasonable to ignore the precautions which can be taken to ensure a comfortable temperature with a minimum of heat supply. Correct choice of building materials can greatly reduce the need for artificial heat. The heat requirements of the enclosed space depend on the quantity of heat lost by passing through the walls, windows, doors, floors, ceilings and roofs, and on the amount of cold fresh air for ventilating purposes entering through openings and gaps.

Tightly closing windows and door frames will reduce the penetration of cold air into the heated space, and infiltration may be needed in order to achieve a certain amount of air change; this is, however, an inefficient method of ventilation, as the amount of air passing increases with the temperature difference between the room and the outside, and changes with the direction and force of the wind. It is far better to control ventilation by making use of special openings and as far as possible to eliminate cracks. Not only windows and doors but also all joints in the construction should be made and kept airtight.

Secondly, the materials for walls, floors, ceilings and roofs should be so chosen that the amount of heat passing through them is kept low and that the inner surface temperature can quickly be brought to a high temperature. To fulfil these conditions the conductivity has to be kept low and the inner surface should be of such a nature as takes up heat quickly and retains it.

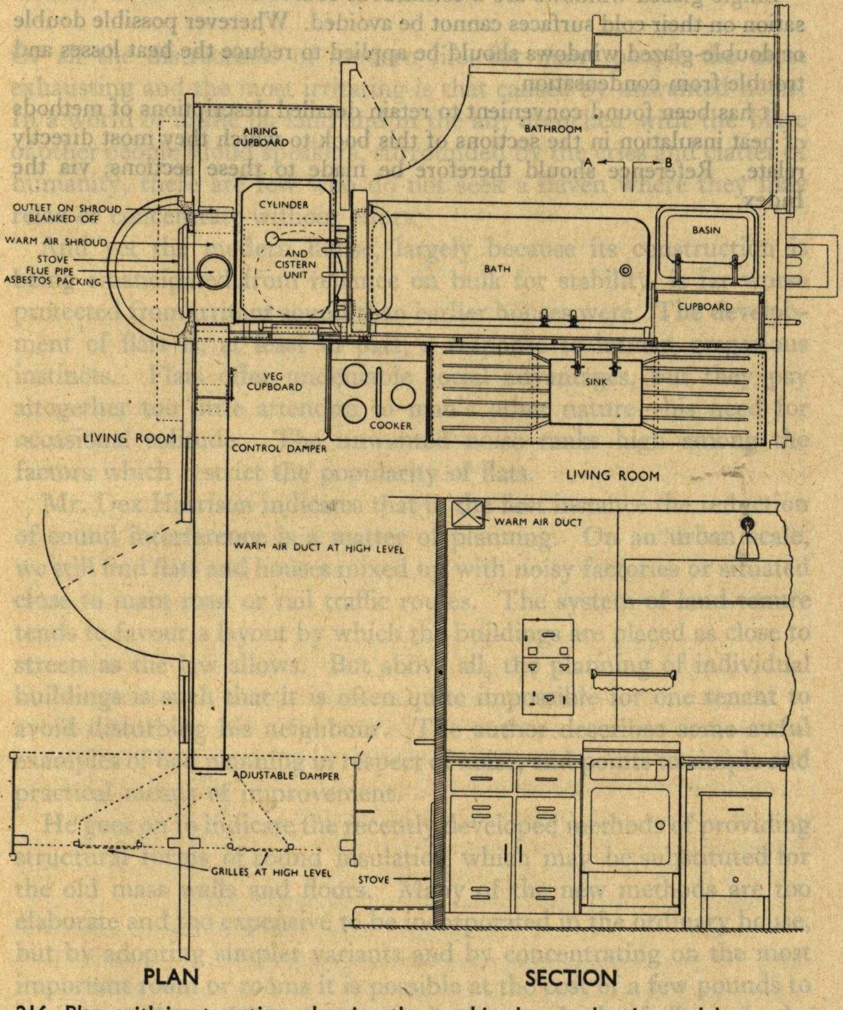
In practice this means a division of function between separate skins of the outside wall, the outer section of which must keep out the weather, and the inner must insulate against heat losses. A closed air cavity between these skins is a very formidable obstacle to the transmission of heat. This is made even more efficient by the incorporation of a metallic foil.

It is now common practice to specify the heat transmission coefficient as not more than 0·3 B.Th.U. per sq. ft. per hour per degree Fahrenheit temperature difference. This figure is applied to external walls, floors and ceilings. Wherever possible it is recommended that this figure should be reduced to 0·15 for walls and floors and to 0·2 for ceilings and roofs. The following figures may serve to give a comparison. The heat transmission coefficient at average conditions for a 9-in. brick wall is 0·44; for an unventilated 11-in. cavity wall this coefficient is as low as 0·29; for a 6-in. concrete wall it rises to 0·5; yet for asbestos sheets ¼-in. thick it reaches 0·8 and for corrugated iron sheeting it even exceeds this value, being 1·04.

These comparisons help to explain why sheeted asbestos and steel buildings without boarding give no comfort in spite of every endeavour to

keep the air temperature at comfort level. By covering the inside of the corrugated iron sheets with 1-in. thick tongued and grooved boards, the coefficient of transmission will be reduced to 0·38.

Other examples: 9-in. brick wall and inside covering of board will reduce the heat transmission coefficient to about 0·25; by using wood studding to provide an air space between the wall and the boarding the improved value of 0·18 will be reached.



216. Plan, with inset section, showing the combined space heating and hot water system installed in the Ministry of Works Temporary Houses. Note the warm air ducts to provide background heating in bedrooms.

Ceilings, roofs and floors should be treated in a similar way. It is common experience that a concrete floor is cold and that wood boarding improves its heat-retaining capacity.

It is particularly necessary to treat the walls of living-rooms, as this reduces the heat losses and the consequent fuel consumption in the most used room of the house. Precautions should also be taken to keep the roof space warm, at least by felting the tiled roof.

Single glazed windows are a continuous source of heat loss as condensation on their cold surfaces cannot be avoided. Wherever possible double or double-glazed windows should be applied to reduce the heat losses and trouble from condensation.

It has been found convenient to retain detailed descriptions of methods of heat insulation in the sections of this book to which they most directly relate. Reference should therefore be made to these sections, via the Index.

SECTION XII

SOUND INSULATION

Of all the distractions of modern life, for many people the most exhausting and the most irritating is that caused by unwanted noise. In a world of traffic on land and in the air, drenched with the blare of other people's loud speakers, surrounded by the cries and clatter of humanity, there are few who do not seek a haven where they may relax or concentrate without effort.

And yet the modern house, largely because its construction is being emancipated from reliance on bulk for stability, is far worse protected from irritant sound than earlier houses were. The development of flats is, at least in part, a response to human gregarious instincts. Flats offer undeniable social advantages, but they pay altogether too little attention to man's other nature—his need for occasional solitude. The unwanted noise ranks high among the factors which restrict the popularity of flats.

Mr. Dex Harrison indicates that in the first instance the reduction of sound interference is a matter of planning. On an urban scale, we still find flats and houses mixed up with noisy factories or situated close to main road or rail traffic routes. The system of land tenure tends to favour a layout by which the buildings are placed as close to streets as the law allows. But above all, the planning of individual buildings is such that it is often quite impossible for one tenant to avoid disturbing his neighbour. The author describes some awful examples of bad planning in respect of noise, and points to simple and practical means of improvement.

He goes on to indicate the recently developed methods of providing structural forms of sound insulation which may be substituted for the old mass walls and floors. Many of the new methods are too elaborate and too expensive to be incorporated in the ordinary house, but by adopting simpler variants and by concentrating on the most important room or rooms it is possible at the cost of a few pounds to achieve a substantial improvement in the standards of silence in the modern home.

SOUND INSULATION

By D. DEX HARRISON, A.R.I.B.A., A.M.T.P.I.

While in most respects the efficiency of buildings has been steadily increasing, one problem, that of controlling noise, has become more and more unmanageable. This is due to two causes. On the one hand, the sources of noise are increasing; the wireless and the gramophone are adding new contributions from within buildings, and traffic of ever-increasing volume and weight is continuously intensifying outside noise. On the other hand, the development of more scientific techniques and the introduction of lightweight structural materials are leading to a reduction in the weight of buildings. As it is broadly true that the noise resistance of a structure improves with its mass, this reduction in weight has been having a serious effect on sound insulation.

From the point of view of sound insulation the perfect structure was the mediæval castle built of solid stone or brick, many feet thick. The most unsatisfactory is the flimsy week-end bungalow. Recent research has led to the development of methods which overcome some of the weaknesses of lightweight structures; this research ranks among the most important being undertaken in the field of building. In this country we are indebted to the National Physical Laboratory at Teddington and to the Building Research Station at Garston, both of which are sections of the Department of Scientific and Industrial Research, for most of the advances which have recently become available.

PLANNING AS A MEANS OF AVOIDING NOISE

The first line of defence against noise lies in good planning. This begins in the widest consideration of town and area planning. If the initial planning is bad no amount of expenditure on structure will avail to rectify faults. As an example of this the case of one well-known hospital can be cited. For reasons of advertisement this hospital insisted on retaining its site at a busy cross-roads; the decision has defied the ingenuity of the architect and sound consultant in their attempts to make the wards quiet and peaceful for the unfortunate inmates.

The first step is to examine the town plan. Noisy industries should be kept well away from housing areas, schools, hospitals and all other buildings whose occupants need quiet. In the older industrial towns in the north, weaving mills and iron foundries were interspersed among the houses, exposing them to the constant hum of industry; sensible zoning

can easily rectify this fault. Nor should buildings be sited along main traffic routes, whether roads or railway lines. Shunting yards are particularly aggravating sources of noise, and buildings which need quiet surroundings should not be placed within a quarter of a mile of any such yard.

On the town planning scale, some protection can be given by the planting of trees or by putting the source of noise in a cutting. As the residents of Southwark and Lambeth know to their cost, an elevated road or railway is the noisiest of all traffic routes. So great was the noise of the old New York elevated railway system that the value of property on either side fell almost to zero.

The earlier attitude to Civic Design with its emphasis on pompous and monumental expression of the road frontage will have to adapt itself if the noise menace is to be kept under control. It has been shown that the normal type of street with buildings fronting on to the pavement is inefficient from the standpoint of noise, since it places the windows in close contact with the source of noise, and the sides of the buildings provide reverberating space which builds up and contains sound instead of allowing it to disperse.

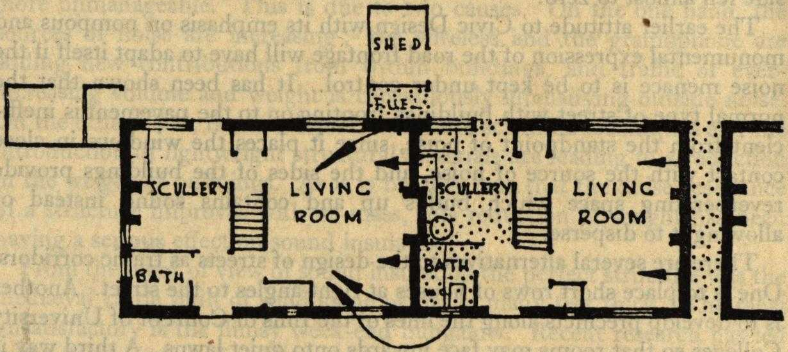
There are several alternatives to the design of streets as traffic corridors. One is to place short rows of houses at right angles to the street. Another is to develop precincts along the lines of the Inns of Court or of University Colleges so that rooms may face inwards onto quiet lawns. A third way is to place buildings in the centre of their sites instead of following the common practice of building them close to the street. Examples of buildings which incorporate this last improvement may be seen in the new University of London and St. James's Underground building. Although this third method in one sense represents the smallest disturbance of traditional site planning, it must be regarded as a counsel of perfection hardly attainable in the central areas of our cities. As long as the land is held in hundreds of very small parcels which compel the owner to develop his road frontage, little can be done ; a pooling of sites would, however, enable entire blocks to be replanned on more efficient lines.

The planning measures which can be taken against noise are not exhausted by the successful siting of a building. Within the building itself the same principles apply—segregation of rooms in which quiet is desired from those likely to prove a source of noise. Each type of building has its special problems ; wards in hospitals and classrooms in schools must clearly be given the most sequestered positions. Here we can only deal specifically with a few domestic examples. These do, however, illustrate the principles common to all buildings.

The rooms in a house can be divided into three categories : quiet rooms—bedrooms : noisy rooms—kitchen, bathroom, W.C., staircase : rooms which are alternately noisy and quiet—living rooms. It is in the living room that the main sources of internal noise—the wireless and

piano—are situated and where noisy games are played and a lot of talking goes on, but the living room also requires quiet for reading and study; this fluctuation in requirements makes the room very difficult to deal with.

Up to the present, house and flat plans have shown little awareness of the noise problem. This has been partly because ways of combating noise within the house had not been elaborated and because people were unaware that the problem could be remedied. If we take many earlier designs at their face value, noise must have been regarded as an Act of God. Figures 217 to 222 indicate the main faults met in common types of

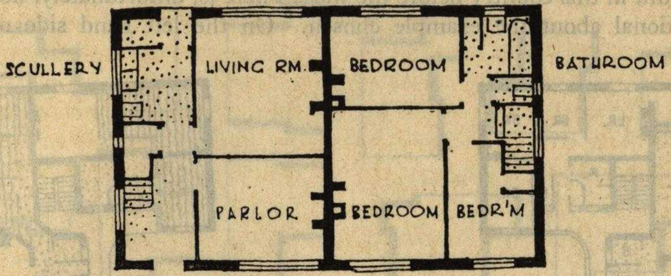


217. Defective planning in small house layout. The noisy scullery, bathroom and fuel store are placed next to the living room. In this and the following diagrams noisy rooms are denoted by dots.

plan and suggest remedies for these faults. Fig. 217 illustrates a living room placed next to an adjoining bathroom and scullery. The clatter of washing-up and the noise of the bath running and being emptied can be heard in the next house. This fault is not an uncommon one in the planning of terraces; an even more frequent fault occurs in nearly all semi-detached houses built between the wars. The so-called "universal" type of plan illustrated in Fig. 218 has two adjacent living rooms which are placed opposite to each other on either side of a 9-in. party wall. Such a division between houses fails to prevent the penetration of the noise of wireless, piano or even the hum of loud conversation. All these sounds are heard to the discomfort of the adjoining tenant; the faults are often aggravated by weakness at the fireplace where the thickness of the dividing wall is reduced to 4½ in. Sound generated in a living room will cause the entire party wall to vibrate and will disturb the occupants of bedrooms in the adjoining house, which in this type of plan are placed along the party wall.

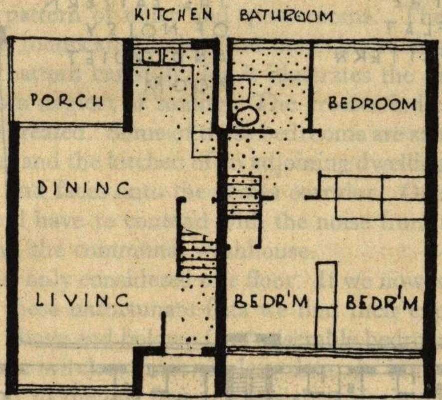
The solution to these troubles in semi-detached houses is to be found in the type of planning illustrated in Fig. 219, which is common enough in the United States. It will be seen that the two living rooms are placed on the side of the house remote from the party wall, which has ranged along it

ancillary rooms such as the bathroom, scullery and staircase. These rooms, although sources of noise, act as buffers between the two living rooms.



218. **The speculative builder's "Universal" plan, the noise defects of which consist of placing living rooms and bedrooms on adjacent sides of a long party wall which is expensive to treat against noise.**

219. **American "Universal" plan reverses the position of the living-rooms and puts the noisy rooms next to the party wall.**

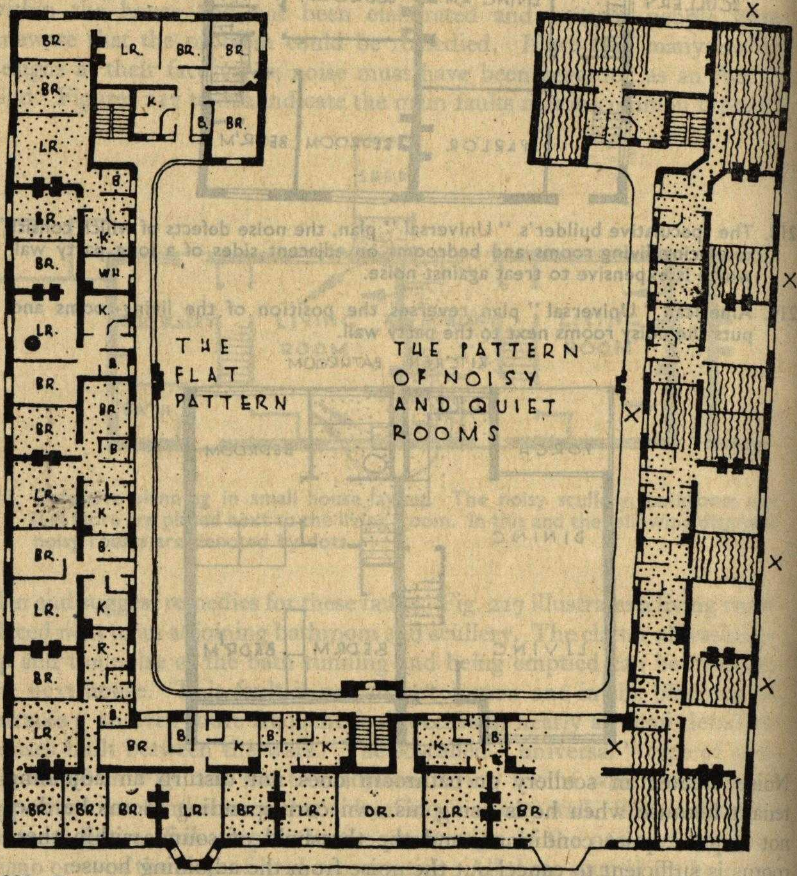


Noise created in scullery or bathroom does not disturb an adjoining tenant because when he is using his own corresponding rooms he does not require quiet conditions, and the threshold of sound within these rooms is sufficient to cancel out the noise from the adjoining house.

With flats all the problems of noise which occur in houses are reproduced in an aggravated form, as the number of separate dwellings which come into contact with each other is increased. It is important to bear in mind that sound travels in all directions and noise in one flat affects the flats above and below as well as those on either side. This obvious point needs emphasis because of the tendency to read plans horizontally and to overlook their vertical relationships.

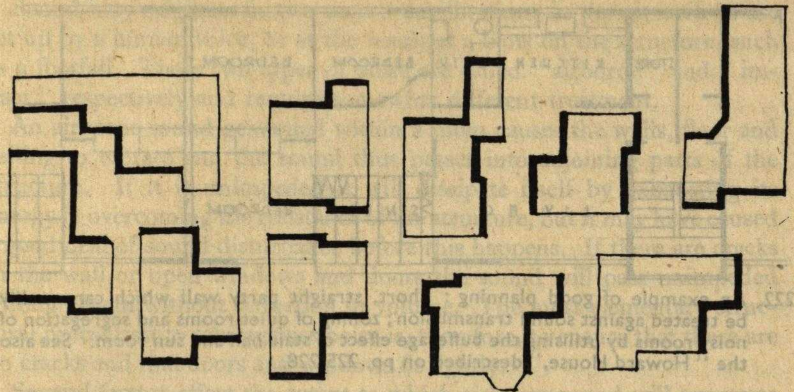
The first consideration in flat planning is to avoid long lengths of party wall. The party wall is always a weak point in the defence against noise,

and the longer it is the more easily noise can pass from dwelling to dwelling. Fig. 220 illustrates an analysis of a typical block of working-class flats built in this country before the war. There is, unfortunately, nothing exceptional about the example chosen. On the left hand side of the



220. Corridor access flats, illustrating all the defects possible in flat design. See the analysis in text.

diagram, flats are shown alternately dotted and plain. In the next diagram (Fig. 221) the plans of individual flats have been drawn separately; this illustrates an astonishing variety of shape and reveals by a thicker line the party walls which bound each flat. In the whole plan there is not one straight party wall and the total length of party wall in the block as a whole is tremendous. Returning to Fig. 220, the right hand side gives an



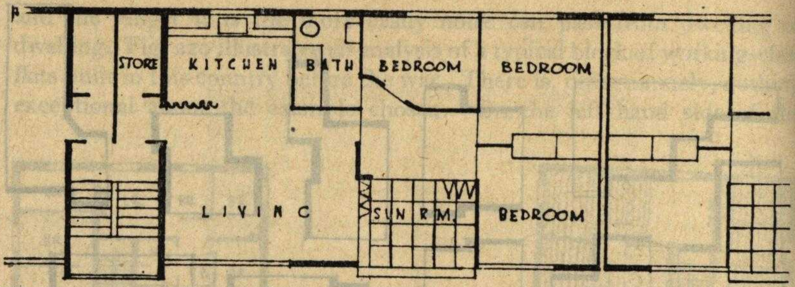
221. Analysis of individual flat plans from Fig. 220. Note the assorted shapes, which give rise to long kinked party walls (shown by thick lines) which are a major source of noise troubles.

analysis of the pattern of noisy and quiet rooms. The noisy rooms are dotted, the quiet rooms are hatched and the living rooms are left white.

Look at this pattern carefully, for it illustrates the dire state of affairs which arises from neglect of zoning. The crosses indicate the bedrooms which are worst treated. Some of these bedrooms are sandwiched between two living rooms and the kitchen of an adjoining dwelling. One is between two bathrooms and faces onto the access corridor. One unlucky wretch, when in bed, will have to contend with the noise from two living rooms, two kitchens and the communal washhouse.

So far we have only considered one floor. If we now look at the vertical relationship of these unfortunate flats we find their exposure aggravated by noisy rooms above and below. One miserable bedroom in this building is exposed to the wireless from no less than six immediately adjoining living rooms and to the din from no less than six immediately adjoining kitchens and no less than three communal washhouses. Remember that sound generated in a wall will travel along it until impeded in some way so as to cause disturbance in a room remote from the actual source.

Such is the measure of the problem so far as it affects flat design. Partly the responsibility must be shared between congestion and incompetent planning. Between the wars far too much stress was laid upon reducing to a minimum the superficial area when the addition of a few square feet, while it would not have increased the cost pro rata, would have yielded rich dividends in more liveable dwellings. An example of a flat of 900 sq. ft. is illustrated in Fig. 222; this flat achieves quite adequate zoning of rooms and has party walls short enough to be treated against noise transmission. It would be better still if the staircase were put at the back between the two kitchens.



222. An example of good planning : short, straight party wall which can readily be treated against sound transmission; zoning of quiet rooms and segregation of noisy rooms by utilising the bufferage effect of stair hall and sun room. See also the "Howard House," described on pp. 225-228.

There is no space here to describe other examples of anti-noise planning for flats, but the use of up-to-date planning techniques can lead to remarkable results. Plans for blocks of flats have been developed which would provide a standard as high as that attained in detached houses; these would justify experimental trial.

THE TRANSMISSION OF SOUND THROUGH STRUCTURES

Sound is the result of a series of disturbances or waves which spread equally in all directions through any suitable medium. It has frequency (pitch) and energy (intensity) though the energy in normal sound waves is very slight. The blast wave of an explosion is a sound wave of extreme violence which has enough energy to demolish a brick wall. This it does by transferring some of its energy to the wall on impact and causing it to vibrate so that it topples over. In the same way, a normal sound, such as a voice, transmits its minute energy to a wall or any other part of a structure and causes it to vibrate, the energy being dissipated mainly in the form of heat. In vibrating, the structure itself becomes a source of sound, like the membrane of a drum; it is in this way that sound may be transmitted from room to room within a building. In addition to acting as a membrane, a material will also transmit sound through its substance by a transference of molecular energy; this applies more particularly to the harder and denser materials such as steel or concrete. It is mainly the higher frequencies which are transmitted in this way.

If one part of a continuous structure, such as a steel or concrete frame, is induced to vibrate as a result of the impact of sound waves or by receiving a blow, the vibration thus set up will traverse great distances along the structure and may penetrate to a remote part of the building. In one case a leaking waste pipe was causing a disturbance at a point several rooms removed from the source and the sound was travelling unimpeded along the continuous reinforced concrete floor.

Sound may originate in two ways ; as vibrations in the air such as are set up by a human voice, or as the result of a blow on the structure, such as a footfall. These two types of noise are called " airborne " and " impact " respectively and require somewhat different treatment.

An airborne sound generated within a room causes the walls, floor and ceiling to vibrate and the sound thus passes into adjoining parts of the structure. If it is unimpeded it will dissipate itself by exhausting its energy in overcoming the resistance of the structure, but it may have caused a good deal of sound disturbance before this happens. If there are cracks in the wall or open windows and doors the sound will pass unimpeded through them without reduction in volume. The most elementary structural precaution to take against noise is, therefore, to ensure that there are no cracks and that doors and windows fit tightly.

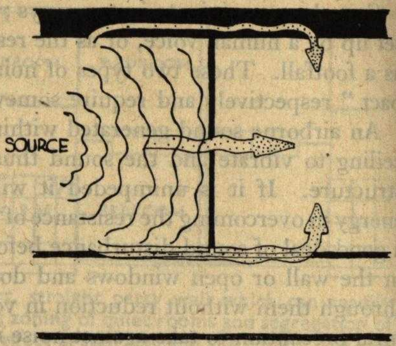
Several factors affect the extent to which airborne sound will penetrate a homogeneous material ; these include the density, hardness of tissue and rigidity of the material. The energy imparted by the sound waves has to overcome the inertia of the material. There is, broadly speaking, a relationship between the unit weight of the material and the volume of sound transmitted ; the heavier the material the less sound it will transmit. It is commonly supposed that materials such as wallboards, lightweight concrete and the light, fibrous, heat-insulating materials provide insulation against noise. This is a complete fallacy. Such materials insulate only in the thermal sense ; as far as noise is concerned they are classed as " acoustic absorbents." This implies that they will not *reflect* sound (which is absorbed in their fibres) but they *transmit* sound to about the same extent as any other material of the same weight. As they are lightweight materials this is as good as saying that they are poor sound insulators.

It has been indicated that the walls of a building transmit sound in accordance with their weight and stiffness. Fig. 223 is an attempt to illustrate this relationship. The main paths for sound are via the thinner and lighter walls which have less resistance, whereas the solid outer wall transmits relatively little. It is clear that most attention has to be given to these light partitions.

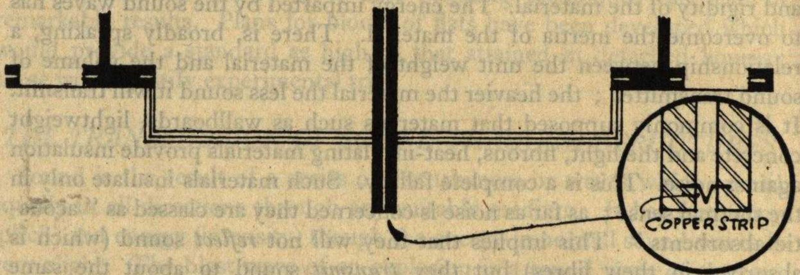
It will be readily understood that if the partition is cut through so that there is a gap in it and it is no longer continuous, vibrations from one part cannot be transmitted to the rest of the partition and the path for sound is broken ; the stationary part of the partition cannot emit any sound. On this simple principle, which is termed " discontinuous structure," sounds can be stopped within a building. A party wall can be made very highly sound resisting if, instead of being built as a 9-in. solid wall, it is built of two skins separated by a 2-in. gap (see Fig. 224), provided that no ties or other solid connections link the two skins.

It is not normally as easy to incorporate discontinuity throughout a building as in the examples illustrated ; it is not, however, always

necessary to provide complete discontinuity. Sound is impeded in its progress through a wall if it reaches a part which is relatively much more solid or heavy, such as occurs where a light partition butts on to a brick chimney breast. It is equally impeded if it reaches a section which is so weak that it cannot transmit the forces set up by the vibrations. In Fig. 224 a copper strip is indicated as closing the end of the wall cavity; this strip would be incapable of transmitting to one leaf of a wall the



223. *The paths by which sound is transmitted through a building, showing the approximate amount of transmission by walls of differing weights.



224. Discontinuous construction. The party wall is built of two leaves not joined in any way and the end of the cavity is closed by a copper strip. A forward extension of the party wall provides bufferage against airborne sound.

vibrations set up in the other. Where only partial discontinuity is achieved we refer to "semi-discontinuous" structure; a very useful degree of sound insulation can be attained by the use of these methods.

Where a high degree of insulation is required it is common to apply the full principle of discontinuity; this is achieved by the creation of a structure "floating" within the main structure. The portion of the building to be insulated is enclosed within a box-like envelope which is more or less completely detached from the rest of the building. It is, as it were, one box within another and is supported at the floor on flexible buffers. A sound created within such a box will cause it to vibrate bodily, but because it has no material connection with the main structure it cannot transmit its vibrations. Similarly, a sound produced in the main structure cannot be transmitted to within the sound-resisting box.

This type of structure is naturally more expensive than an untreated structure would be but it provides a means of incorporating a very high standard of sound insulation. Somewhat cheaper forms of construction involving the same principles have been worked out. These provide a

* Figs. 223, 226 and 227 are based on illustrations in "Sound Transmission in Buildings," by Fitzmaurice and Allen. H.M.S.O., 1939.

lining to the structure of lath and plaster or skimmed wallboard, supported on battens from the walls and with the battens in turn insulated by strips of felt or similar absorbent. Such a lining, used in conjunction with one or other of the types of " floating " floor (having a sub-floor supported on a quilt of resilient material such as eel grass), gives very satisfactory standards of insulation and is recommended for the treatment of living rooms in houses or flats.

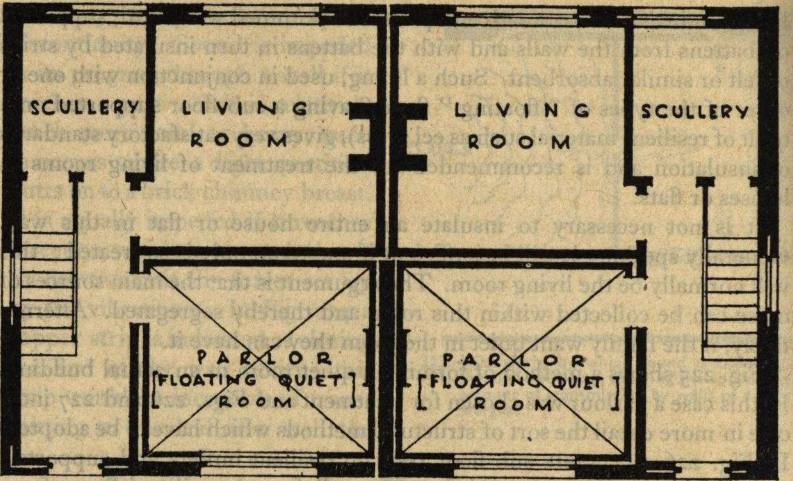
It is not necessary to insulate an entire house or flat in this way. Generally speaking it will be sufficient if one room only is so treated ; this will normally be the living room. The argument is that the main sources of noise can be collected within this room and thereby segregated. Alternatively, if the family want quiet in the room they can have it.

Fig. 225 shows a method of forming a quiet room in an actual building. In this case a parlour was chosen for treatment and Figs. 226 and 227 indicate in more detail the sort of structural methods which have to be adopted. In Fig. 226 a concrete sub-floor rests on resilient buffers and supports a partition set free from the main structure. Below, the ceiling is hung from the main floor by light steel rods. Fig. 227 shows a cheaper form of floating floor built of timber with battens resting on a resilient quilt.

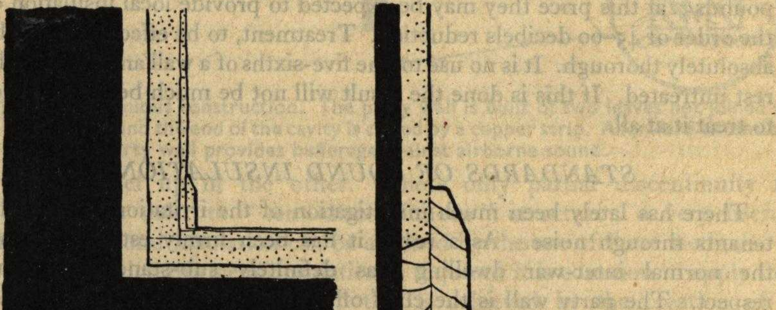
If intelligently designed, sound-treated rooms such as those outlined above should not put up the cost of the dwelling by more than a few pounds ; at this price they may be expected to provide local insulation of the order of 45–60 decibels reduction. Treatment, to be effective, must be absolutely thorough. It is no use to line five-sixths of a wall and to leave the rest untreated. If this is done the result will not be much better than not to treat it at all.

STANDARDS OF SOUND INSULATION

There has lately been much investigation of the irritation suffered by tenants through noise. As a result it has been firmly established that the normal inter-war dwelling was definitely sub-standard in this respect. The party wall is the chief offender and the offence, in that it infringes the privacy of the home, is as much psychological as physical. Exception is taken to quite small noises, such as the raking out of the neighbour's fire or the clicking of an electric switch, although, as could be expected, the main causes of complaint are the wireless and, in flats, impact noises due to people walking above. In a certain flat I recollect hearing the click of an electric light switch in an adjoining flat and a moment later the movement of a bed. " Ah," said my host, " Mrs. So and So going to bed." I felt, thereafter, indecently exposed in that flat. I moved silently and gingerly and I spoke in hushed whispers. When the wireless was put on even softly I was in constant dread of that knock on ceiling or floor which would imply that Mr. So and So above resented the noise. Undoubtedly this was a most uncomfortable flat. Others with more



225. **Parlours treated as discontinuous structural boxes within the main frame of the building.**



226. 227.

Two sections showing ways of achieving discontinuous box structures. 226 shows a complete box, 227 a timber floor " floated " on a resilient quilt.

pungent powers of expression have had the same feelings. Bernard Shaw, in one of his prefaces, wrote :

"If I had to live my life over again I should devote it to the establishment of some arrangement of headphones and microphones or the like, whereby the noises made by musical maniacs should be audible to themselves only. In Germany it is against the law to play the piano with the window open. But of what use is that to the people in the house ? It should be made a felony to play a musical instrument in any other than in a completely sound-proof room. The same should apply to loudspeakers on pain of confiscation."

Some of the defects outlined above are simply due to noisy equipment and, at the cost of a pound or two per house for quieter fitments, are easily remedied. The installation of reasonably quiet fittings in any dwelling should be made compulsory. In spite of this, however, it is the structure itself which is primarily responsible for sub-standard conditions.

The effect of sound upon the human ear is very complex. The ear, for instance, hears only a certain range of pitch ; it has upper and lower thresholds in respect of both intensity and pitch, and is affected differently by shrill and low notes, concords and discords. The ear is very sensitive to faint sounds, but the intensity of a sound must be at least doubled for the ear to recognise a change. Scales have been devised which measure the intensity of sound and its loudness to the hearer. These are called phon or decibel scales ; for our purpose these are the same. The phon scale places all sounds in order of their loudness. The change in intensity which doubles the value of a sound on the phon scale does not, however, seem twice as loud to the hearer. It is important to recognise that the phon scale is on a purely physical basis and that the subjective loudness does not follow this scale. A change of intensity of 1 decibel is about the least that the ear can recognise, though for practical purposes a change of 5 decibels is the minimum significant change.

Approximate values of the commoner sounds have been plotted on the phon scale ; a few examples are given in the following Table :

	Phon Equivalent
Threshold of painful sound	130
Arterial roads	100
Loud radio, noise in tram or bus ..	70
Conversation	50
Quiet suburban street	30
Quiet garden	20
Whisper	10

It is next necessary to know what standards of quiet are needed by people engaged on various tasks. This, too, is complicated by the fact that the loudness of background noises determines the intensity which a super-

L*

imposed noise must have to be noticeable. Thus, if there is a background noise of 40 phons in a room and a new noise also of 40 phons intensity is introduced, the ear will not detect a noticeable increase. In such circumstances the minimum new noise which will be noticed is 45 phons. If, however, the background noise is only 10 phons and a noise of 40 phons is introduced, it will be heard very plainly and may cause great annoyance.

Standards of quiet have been provisionally put forward ; these take into account the amount of background noise to be expected, the work being done and the loudness of noise to be tolerated. In a typing office, for instance, a background noise of about 60 phons will already be present and it will be pointless to insist that the penetration of external noises should be kept below this figure. In contrast, a sick person in a hospital ward will be disturbed by any noise much greater than 15 phons.

If, then, we know the loudness of the sources of sound and the standard which can be allowed inside the building, having regard to its particular use, we require only to know the insulating value of various forms of construction and the buffering effect of distance in order to compute with reasonable accuracy the noise conditions which will obtain in the building. We shall thus be in a position to state whether the building will be adequate for its purpose and to design it to be so. This represents an invaluable advance in building technique ; it is expected that, in the future, noise specifications as accurate and definitive as heating specifications will be demanded in every new building. Whether they notice it or not, occupants will derive considerable benefit from the adoption of such specifications.

The effectiveness of insulation against outdoor noises depends chiefly upon window design. An open window will let in all outdoor noises. When closed, the effectiveness of the window depends upon the weight of glass used, thin 20 oz. sheet giving 28 decibels reduction and ¼-in. plate giving 35 decibels reduction. Where the expense of double glazing can be justified, as may be the case in hospitals, a very high standard of sound insulation can be obtained, up to about 60 decibels reduction. This may be illustrated by an example of a hospital situated a hundred feet from a main road with a bank of trees intervening. The noise at kerb will be about 90 phons ; a reduction of 5 phons can be allowed for the trees and 10 phons for the distance that the sound has to travel to reach the building, bringing the noise down to 75 phons. Double ¼-in. plate glass glazing would reduce this to 15 phons, which is a suitable standard of quiet for a hospital ward provided that the windows are kept shut.

Existing house construction usually consists of 9-in. party walls and 2-in. or 3-in. breeze partitions or 4½-in. brick partitions. With the internal plastering these give reductions of 50 decibels, 35-40 decibels and 45 decibels respectively ; these are inadequate and give rise to complaints. As a result, the Acoustics Committee of the Building Research Board have suggested in their report on Sound Insulation and Acoustics (Post

War Building Studies, No. 14) a reduction of 55 decibels for party walls (i.e. 5 decibels better than the standard of the solid 9-in. wall) and of 45 decibels for partitions between the quiet room in a house and the other rooms. These are put forward as minimum standards and represent some improvement on existing practice. The result should be that a neighbour's wireless blaring at 70–75 decibels will be reduced to a maximum of 20 decibels in the adjoining tenant's bedrooms; this is just adequate, desirable standards for sleeping being from 15–20 decibels. It has not been found practicable to suggest that within the individual house noise should be reduced to a level which would prevent disturbance; the family must still mute their music if some members are asleep or studying.

Impact noises on the floor are dealt with in a rather different manner. In this case the method is to consider some standard form of construction and to fix a standard of sound insulation to achieve a certain level of improvement over the untreated standard. This device is necessary because of the great range of energy which can be conveyed to the structure by impact. The minimum standard proposed is 15 phons reduction over a bare concrete floor or 20 phons reduction over a bare timber floor; this standard is intended to apply as between one dwelling and another and more particularly as between a living room in one dwelling and the bedrooms in another.

It is hoped that these standards will be applied to all post-war houses. Their adoption will ensure a certain improvement over pre-war standards, but even so conditions will still not be as satisfactory as they once were. The deterioration in sound insulation has now continued for so long that it is first necessary to stabilise the position before advancing to new goals.

It must be admitted that the increased use of new structural methods which lead to buildings lighter in weight and therefore potentially more noisy than normal structures constitutes a serious problem in sound insulation. Perhaps the worst offenders are steel structures because of the readiness with which steel conducts noise. This article has indicated ways by which noise can be kept down, even in prefabricated buildings, but the insulation standards are virtually predetermined by the initial design. Whenever a modern structure is under review, the question of sound transmission must be scrutinised with care.

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SECTION XIV

ELECTRICAL EQUIPMENT

OTHER sections have dealt with the use of electricity for the purposes of lighting and of heating. In the not very distant past, this would have exhausted the ways in which electricity could be used in the home. As Mr. Pawsey describes in the following Paper, the situation is now radically changed. In the form of the heating element and of the small electric motor, electricity is able to help the housewife and her family in a hundred ways.

The author points out, however, that a rational and efficient use of the new apparatus is dependent on the reorganisation of the method of wiring and on the standardisation of accessories. Successive additions have been made to the wiring of most older houses, so that they now contain a maze of cables and fuse boxes. Even many of the most recently built houses have circuits which display few signs of rationalisation. He believes that the adoption of the ring-main system, combined with an adequate number of fully interchangeable socket outlets, will pave the way to a greatly improved service. Many of the traditional troubles, such as groping in the dark when a main fuse blows, can thereby readily be eliminated.

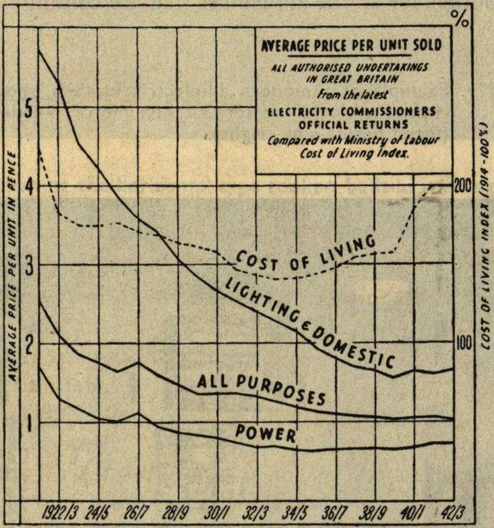
One of the greatest assets of electricity is its flexibility. It would be a pity to carry standardisation of equipment to the point at which this advantage is sacrificed. Apart from giving scope for the preferences of the individual, the provision of socket outlets for portable apparatus will not freeze the equipment at this particular stage of development.

The author works systematically through the many intriguing accessories which are already available in this country and elsewhere. He also discusses the prospects of such revolutionary devices as the electronic cooker, which can roast a joint by high-frequency waves in a matter of a few seconds. He comes to the conclusion that this last appliance, which is still far too expensive for home use, will have to overcome considerable sales resistance before being at all widely adopted.

ELECTRICAL EQUIPMENT

By OWEN PAWSEY

THE expansion of electrical services in the home has been rapid. At the end of the first World War there were less than a million domestic consumers in Great Britain. By 1939 that number had increased to 9½ millions, and it is estimated that in a few years time all but the most isolated homes will have been connected to the mains. The price of the unit decreased steadily in the period between the wars, and has remained comparatively steady since, in spite of the increased cost of coal. Fig. 228 shows the drop in the average price per unit sold for lighting and domestic purposes from over 5d. in 1922–3 to about 1½d. now, and compares this with the rise in the cost of living.



228. Graph shows how the price per unit of electricity remains at a low level despite the increase in the cost of living.

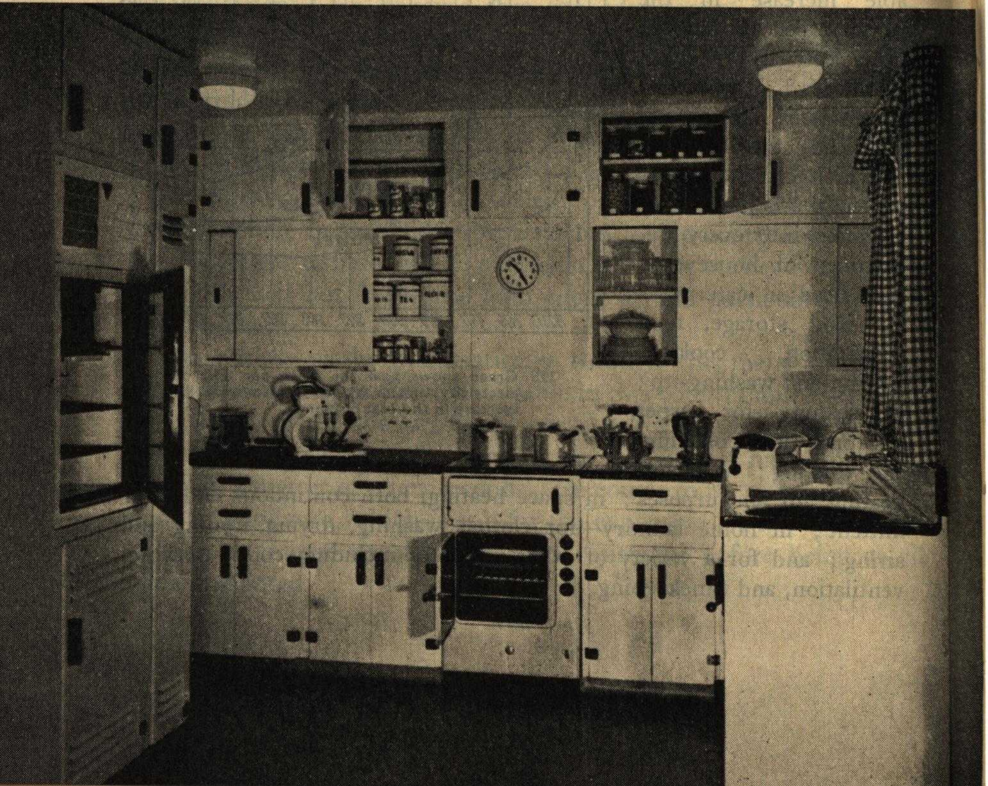
Coincident with the extension of supply facilities in Great Britain, there has been considerable increase in the variety of services derived from electricity. Whereas, at the end of the first World War, lighting was practically the only use to which electricity was put in the home, to-day it enters into every department of housework. It is used in catering—for food storage, food preparation, cooking, serving and washing-up ; in cleaning—for carpet sweeping, floor polishing, and dusting ; in water heating, for all purposes ; in space heating, both continuous and intermittent ; in home laundry—for clothes washing, drying, ironing and, airing ; and for a variety of other purposes including communication, ventilation, and timekeeping.

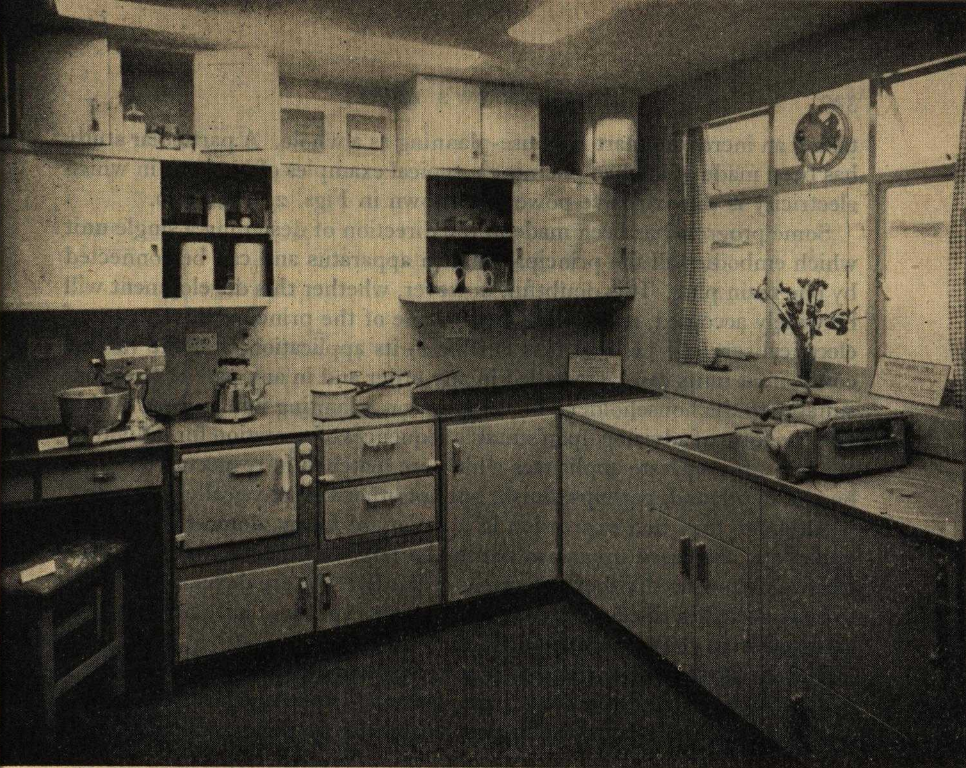
It is possible, therefore, to look at the future from an entirely new aspect. Instead of a miscellaneous collection of appliances, we now have one comprehensive household service from a single main. That must certainly have an important bearing upon future house planning.

Standardisation of apparatus has been considerably assisted by the general change-over to a system of supply at 230 volts A.C. In the design of the appliances themselves there has recently been a large measure of agreement upon interchangeability of working parts and "consumable" parts such as motors and elements; there is hope, too, of evolving a standard form of socket-outlet and plug to supersede the confusing assortment of 2-amp, 5-amp and 15-amp accessories at present in use.

In the absence hitherto of any planned development of the electric home it is inevitable that anomalies still exist. Installations which were sufficient for the needs of the nineteen-twenties are now out-dated, and not the least of the difficulties facing those responsible for future housing is the provision of a wiring system which will have an adequate number of outlets for all the appliances that are coming into use.

229. Example of a modern all-electric kitchen, showing built-in refrigerator, synchronous clock, roaster, kitchen motor, kettle, cooker and washing machine (fitted beside sink, right).





230. Another electric kitchen, showing the horizontal type cooker, built-in washing machine beside the sink and extractor fan in the window.

A committee convened by the Institution of Electrical Engineers which has been studying this question at the request of the Ministry of Works* has advised the following minimum specification :

Living Rooms : 3 socket outlets.

Double Bedrooms : 3 socket outlets.

Single Bedrooms : 2 socket outlets.

Kitchen : 3 socket outlets (or 2 if the kitchen is not for use as a living room). In addition, one connection for a cooker and one connection for a refrigerator.

Not Located : One connection for a water heater, and socket outlets for laundering according to the facilities required.

One result of the comprehensive character of electrical service is that the Electrical Industry has been able to identify itself more intimately with the architectural profession and building trade, and, through such organisations as the British Electrical Development Association, has lately been

**Post-war Building Studies, No. 11, "Electrical Installations"* Ministry of Works (H.M.S.O.).

taking an increasing part in house-planning as a whole. A particular study has been made of kitchen planning ; typical examples of kitchens in which electricity is the exclusive power are shown in Figs. 229 and 230.

Some progress has been made in the direction of designing a single unit which embodies all the principal kitchen apparatus and can be connected by one main plug. It is doubtful, however, whether this development will be widely accepted, as it largely rejects one of the principal advantages of electrical service—i.e. that it is flexible in its application, and the various component units can be installed in any order and in any part of the room suitable to the householder. For that reason, planning will more probably take the form of advising upon suitable sequences of operation for individual needs, using separate appliances which are matched in respect of working height, depth and, perhaps, finish, but not otherwise physically connected.

Although they find expression in a variety of forms, domestic electrical appliances are based upon two items, the resistance heating wire and the electric motor, used either separately or jointly. Future developments are to be expected in the field of electronics, but as yet these have not properly emerged from the experimental stage.

Mainly owing to the strong influence of electricity supply undertakings in the sale of appliances in Great Britain, there has perhaps been a tendency to put more emphasis on the heavier current consuming appliances such as cookers, water heaters and washboilers. Nevertheless it is true that the lighter-loaded motor driven appliances are able to contribute most to the reduction of housework, and it is probably in that direction that the most rapid development will take place in the immediate future.

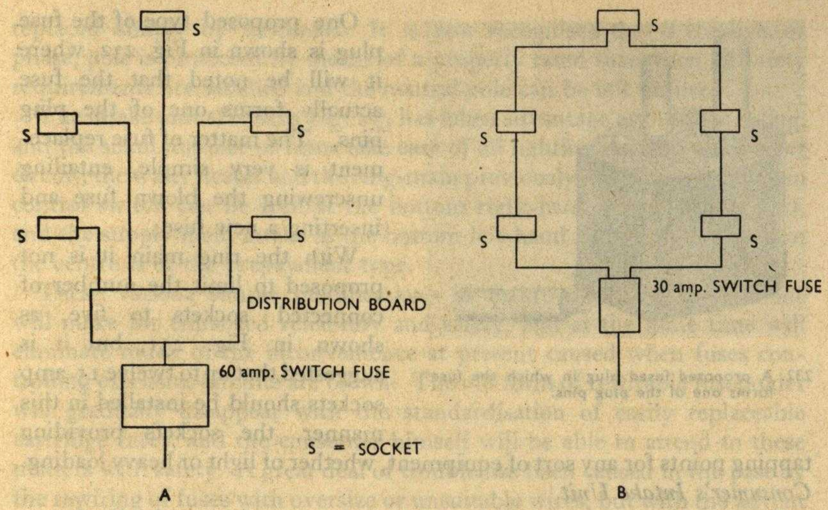
WIRING INSTALLATION

In the main the physical construction of the electrical installation of the immediate future will follow closely on pre-war practice—that is, steel conduits will be found on the majority of installations. Several non-metallic systems are under development, but until the final form of the construction of the standard house is known, these will probably remain in abeyance.

Vulcanised india rubber insulated cables will be used to a considerable extent, depending upon rubber supplies. The wartime substitute insulation for cables, polyvinyl chloride (P.V.C.), has exhibited such valuable features in practice that it will probably rank as an alternative rather than as a substitute. At present this type of cable is rather more expensive than the rubber insulated variety, but increasing demand may correct this.

Circuit Arrangements

For the smaller houses, considerable modification of circuit arrangements will be made, designed to take advantage of diversity of use of domestic appliances, a matter that has been neglected in the past. For



Standard arrangement for five heating sockets — Proposed new arrangement for five heating sockets

231. PRESENT AND FUTURE WIRING CIRCUITS COMPARED

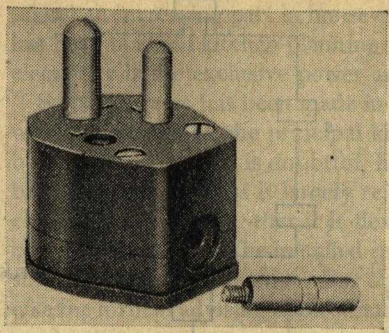
instance, under pre-war regulations, the installation of five 15-amp sockets of the type used for electric heating circuits would have necessitated a separate fuseway on a distribution board for each socket, as shown in Fig. 231A. It will also be seen that this large distribution board is controlled by a 60-amp switchfuse, and a separate run of cable, probably 7/·029, is necessary between the distribution board and each socket.

Under the proposed modification, known as the "ring main," Fig. 231B, the circuit commences with a 30-amp switchfuse, from which a continuous ring of similar cable, 7/·029, passes through each of the five sockets in turn, the ends being finally connected back into the switchfuse. The economy in conduit, wiring, etc., will be clear from the comparison of the diagrams, whilst the distribution board is eliminated altogether and a smaller switchfuse used.

Individual Protection

To provide for individual protection for the sockets against overload or short-circuit on the connected equipment, fuses are installed in each plug,* arranged for easy replacement by the consumer. Thus, in the event of fault, only the affected equipment is isolated, and an alternative radiator or other appliance can immediately be plugged back into the socket. By the use of suitably rated fuses, standard lamps may be used with safety from any socket designed for heating or any similar heavy demand.

*The British Standards Institution has proposed up-rating the existing 5-amp plug to 13-amps and installing a fuse in the socket, but the suggestion is not approved by installation engineers.



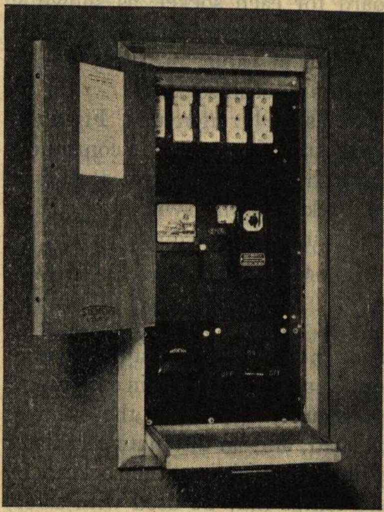
232. A proposed fused plug in which the fuse forms one of the plug pins.

One proposed type of the fuse plug is shown in Fig. 232, where it will be noted that the fuse actually forms one of the plug pins. The matter of fuse replacement is very simple, entailing unscrewing the blown fuse and inserting a new fuse.

With the ring main it is not proposed to limit the number of connected sockets to five, as shown in Fig. 231, but it is suggested that up to twelve 15-amp sockets should be installed in this manner, the sockets providing tapping points for any sort of equipment, whether of light or heavy loading.

Consumer's Intake Unit

Another improvement will be the introduction of a standardised type of consumer's intake unit, in which the supply main service, the meter, and the fuse group for cooker, ring main and lighting circuits will be located. One type of intake installed in Northolt demonstration houses by the Ministry of Works is shown in Fig. 233. Its remarkably neat arrangement, sunk into the wall and concealed by a wooden frame and door, will be appreciated. On the production models the individual fuses will be labelled, although with the use of plug-fuses the necessity for looking for blown fuses in darkness will, to a great extent, be eliminated. It is proposed that the units shall be built into houses during erection.



233. Consumer's intake unit, new design.

In any case, fuse and distribution boards will contain only half the number of fuses found in previous fuse-boards, as official regulations now approve the fusing of one pole of the circuit only, as against both poles called for in earlier rules. This means that only one row of fuses will be found instead of the more familiar double row, the second being

replaced simply by terminals. It is now recognised that if the live, or phase, pole is protected by means of a properly rated fuse, then all safety requirements are satisfied and the neutral pole can be left unfused.

The intake unit shown in Fig. 233 has taken advantage of this new ruling, and the small number of fuses take care of all lighting circuits, the cooker circuit, the water heater and the ring-main previously described. The main control switch can be seen at the bottom right-hand corner of the unit, and the supply main intake at the bottom left-hand corner ; the meter in the centre is of the prepayment type.

These various simple modifications in future electrical installations will make for enhanced reliability and safety, and at the same time will eliminate much of the inconvenience at present caused when fuses controlling extensive circuits are blown. The old form of rewirable fuseholder will gradually disappear with the standardisation of easily replaceable cartridge fuses, and the consumer himself will be able to attend to these matters with safety. A great deal of trouble has been caused in the past by the rewiring of fuses with oversize or unsuitable wires, but with the advent of cartridges this difficulty should disappear.

Non-Rigid Conduit

The development of non-rigid conduit, preferably non-metallic types, is forecast as representing extreme simplicity in installation with the elimination of that expensive and labour-wasting adjunct of rigid steel conduits—cutting away and making good. It may also require a somewhat lower standard of skill for installation, which will be important if the large number of houses required are to be completed in a short time. Steel conduit installation demands a high standard of workmanship for its efficient operation, and it is more than probable that a sufficient quantity of this standard will not be immediately available.

Owing to the rubber shortage it is unlikely that tough-rubber sheathed wiring systems will reappear, although P.V.C. substitutes may be used. For the same reason, lead-covered wiring systems may be too expensive for general adoption. The recommendation in Post-War Building Studies No. 11, *Electrical Installations*, issued by the Ministry of Works, is for steel conduit, heavy gauge screwed or light gauge brazed, with V.I.R. or P.V.C. cables and most present-day accessories. It is also recommended that the existing standard for sockets and plugs should be abandoned in favour of the all-purpose socket and fused plug.

SWEEPING AND CLEANING

A big advance is to be expected in the application of mechanical electrical appliances to the tasks of cleaning and sweeping. Mechanisation of housework began with the suction cleaner and this remains the most widely used machine. Domestic models are either of the upright or " broom " type

with external dustbag and revolving brush, or the horizontal type with internal dustbag, with which the cleaning action is by suction combined with manual brushing. A few of the former kind also incorporate a beating and cushioning action to facilitate loosening the dirt in the carpet, and help to draw the dirt also from the underside.

Large scale suction systems, having one central motor and a system of ducts to the wainscotting of the various rooms in the building, have been used in industry and could reasonably be applied to blocks of flats, but it is doubtful whether any worthwhile saving or advantage accrues.

Less progress has been made towards applying mechanical processes to the cleaning of other surfaces such as plain and polished wood floors, linoleum and paintwork. Accessories provided with the vacuum cleaner can be used for dusting parts of the room normally out of reach, and a handy lightweight machine which can be carried in one hand is now available for suction-cleaning upholstery, staircarpets and places normally inaccessible to the larger machines.

Domestic floor-scrubbers may follow the successful introduction of such appliances on a large scale in industrial and office premises. As far as we know at present there is no floor-scrubbing machine made specifically for use in the home. The smallest model available before the war was designed to deal with 3,000 square yards of floor space per hour.

The increasing interest in parquet and other polished floors in recent years has drawn new attention to the domestic floor-polisher, and more of these appliances will be available. Apart from the machines designed solely for this service, there are floor polishing devices supplied for fitment to certain makes of vacuum cleaner.

It is appropriate to refer here to the possible future development of air cleaning which aims at trapping dust and dirt while it is airborne, so reducing the amount of dusting and cleaning necessary. At present such systems are still in the early stages of development and have been installed in industry only on a small scale.

In its simplest form the air cleaner is an electric extractor fan incorporating a close-mesh filter and used as part of a mechanical ventilating system.

A more advanced system by the electrostatic method is now being tried out and may eventually find some application in simpler form for domestic use. Particles as fine as 1/250,000 of an inch are trapped by this method. A typical unit consists of three major parts—the dust collector cell, the ionizer unit and the power pack. The ionizers are energised by the power pack with 13,000 volts D.C., creating a strong electrostatic field. As the air passes through this electrostatic field, every particle of foreign matter, regardless of size or make-up, receives a positive charge. Within the area of the cell itself (known as the collector) are parallel plates alternately charged with 6,000 volts D.C. and spaced $\frac{5}{16}$-in. apart. Since

unlike charges attract, the positively charged dust particles collect on the negative plates.

Where electrostatic air cleaning is installed, the period between redecorating is lengthened, high dusting is reduced and draperies, furniture and other appointments stay clean longer.

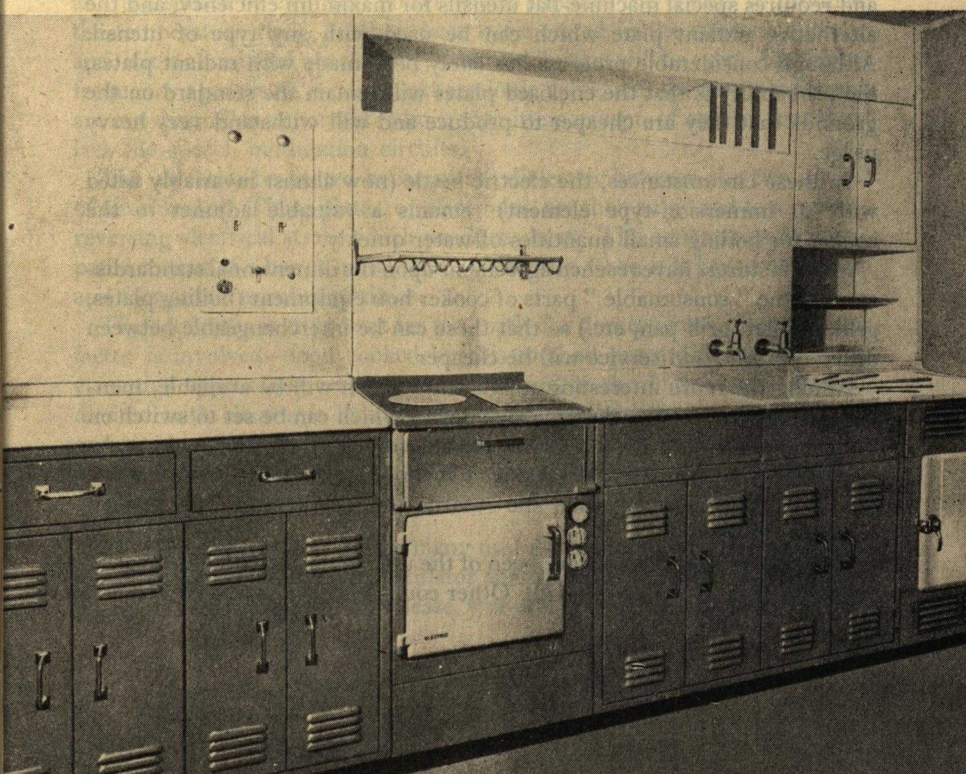
CATERING SERVICES

By far the greatest number of domestic electrical appliances have been designed for catering service. The kitchen of the future can have equipment to assist in the storage, preparation, cooking and serving of food.

Electric Cookers

The electric cooker of to-day is a vastly improved appliance compared with its counterpart of only a few years ago. Apart from increased efficiency, faster boiling and finer adjustment of temperature, the general appearance has been improved by cleaner line, the introduction of lighter and coloured surfaces, and the greater use of sheet steel in place of heavy castings.

234. Ministry of Works kitchen unit for emergency factory-made houses showing the standard electric cooker, refrigerator and general control panel.



The cooker designed as a co-operative venture by British manufacturers for M.O.W. emergency factory-made houses is a good indication of what may be expected as standard equipment in future. It is shown in the M.O.W. kitchen unit, Fig. 234.

On the hob, there is one solid enclosed 3-circuit 8-in. boiling plate with four-heat control, and a griller-boiler loaded to 2 kw. Top loading on the boiling plate is 2 kw. and this goes down in two steps to simmering at 220 w. The griller-boiler has a grill pan adjustable to three alternative heights. A drop-down door gives access to a warming cupboard approximately 18-in. wide, 14 in. deep, and 5½ in. high, and the walls and floor are so constructed that spilt liquids from the hob and cupboard collect conveniently in a groove at the front. Oven capacity is 2,200 cu. in., the dimensions being approximately a 13-in. cube. There are three plug-in elements totalling 2,400 w. and distributed as between 1 kw. at each side and 400 w. at the bottom. Oven heating is thermostatically controlled and has a pilot lamp indicator. For easy cleaning, the oven interior is removable in three parts.

A glance at this specification shows the advance that has been made. For instance, before the war thermostatic oven control and a simmer heat on the boiling plate were regarded as extras ; now they are standard equipment.

There is a tendency towards higher loadings for boiling plates—one prototype is rated at 4 kw.—but as yet there is no general agreement on the issue between the enclosed plate which heats mainly by conduction and requires special machine-flat utensils for maximum efficiency, and the alternative radiant plate which can be used with any type of utensil. Although considerable progress has lately been made with radiant plates, the probability is that the enclosed plates will remain the standard on the grounds that they are cheaper to produce and will withstand very heavy usage.

In these circumstances, the electric kettle (now almost invariably fitted with an immersion-type element) remains a valuable adjunct to the cooker for boiling small quantities of water quickly.

Manufacturers have reached agreement upon the dimensional standardisation of the " consumable " parts of cooker hob equipment (boiling plates, griller boiler, grill pan, etc.) so that these can be interchangeable between different makes and service will be cheaper.

Among the more interesting refinements which will be available, mention can be made of the electric clock device which can be set to switch on the oven and switch it off again at predetermined times, thus making the cooking process entirely automatic. Having " loaded " the cooker, the housewife can go out: when she returns the meal will be fully cooked and ready to serve.

Hitherto British cookers have been of the upright type, with oven placed below the hob and hot cupboard. Other countries have shown preference

for a horizontal model with raised oven alongside the hob. With this latter style, the main difficulty in Great Britain has been to get sufficient space for it in the kitchen ; the cooker requires at least 42 in. of wall space, and most kitchens in houses built in the last quarter of a century made no allowance for this. Now, with the tendency to revert to larger kitchens in future, manufacturers have jointly agreed to add the horizontal type to their productions. One such cooker is shown installed in the kitchen, Fig. 230.

Electronic Cookers

Looking further ahead, there is the possibility of electronics being applied to electric cooking. The introduction of high-frequency heating in certain industrial processes has led to the adaptation of this system to large scale cooking. The main advantages are that cooking is uniform and is completed in a matter of only a few seconds.

With the normal form of electric cooking, heat is applied to the outside first, and the interior of the substance is heated to a greater or lesser degree according to its capacity as a thermal conductor. If the substance being heated (cooked) happens to be thick, there may be an appreciable temperature difference between the inside and the outside, and the regulating temperature becomes a matter of compromise.

Entirely different conditions are involved in electronic, or high-frequency, heating. There is no direct contact between the object heated and the source of electrical power which supplies the energy to produce the temperature rise. Further, heat is generated in the substance itself, and, if it is of uniform consistency, heat distribution will be even. The high-frequency agent is an oscillating thermionic valve, and the heat generators are not dissimilar to normal radio transmitters except, of course, that they lack the speech modulation circuits.

The object to be heated becomes the dielectric between the two plates of a condenser. Those plates, or electrodes, are then subjected to a rapidly reversing electrical strain which produces heat. The action may be compared to that of a bar of metal which warms up when it is bent backwards and forwards a number of times.

The apparatus is at present far too costly for domestic use. But another factor is involved—food cooked by this method has a different and less attractive appearance. For instance, bakers in the U.S.A. who experimented with electronic baking, had to return the bread to normal-type ovens to give it a " crust " ; people did not like crustless bread. Similarly meat was refused because it lacked the customary browning on the outside.

Table Appliances

Allied to electric cooking are many useful table appliances, of which the most popular are the coffee percolator and the toaster. Automatic toasters, incorporating a timed spring release, will probably come into wider use.

Kitchen Motors

In the preparation of food, the fractional horse-power motor is due to take a bigger part in the immediate future. With the aid of various accessories, the kitchen motor (shown on the left in Fig. 229) will act as whisk, mixer and beater; moreover, the work is done more efficiently and quicker than by hand. An associated motor-driven device coming from the U.S.A. is a garbage destructor which, fitted into the waste outlet of the kitchen sink, minces up all normal kitchen refuse into a mash and allows it to be swilled down the drain.

Washing-up Machines

Experiments are proceeding to find a suitable machine which will undertake what is perhaps the most tedious of all household tasks, washing-up. Domestic models have been produced which will not only wash and rinse, but, by an automatic changeover switch, connect up a heater for drying. In no case, however, has it yet been possible to produce washing-up machines at a price which will make them available to the public in general, and some years must pass before we can expect to see them in wide use. An associated problem is that they demand a liberal supply of hot water, a service which most homes cannot yet give.

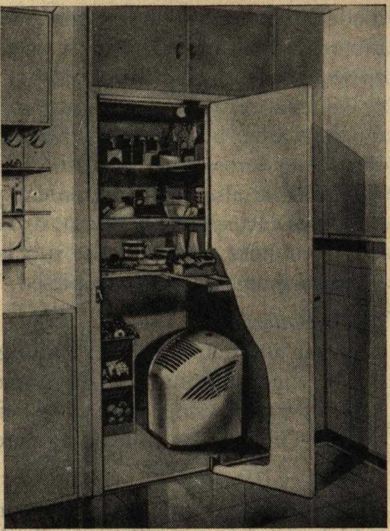
Refrigerators

For food storage and preservation, there is every indication that refrigerators will become commonplace in British homes in the immediate future, and manufacturers have planned for production on a far larger scale than hitherto. Two systems of refrigeration are available: (a) the mechanical units based upon a motor driven compressor, and (b) the non-mechanical units, having a heating element and obtaining refrigeration on the absorption principle. Nearly all electric refrigerators are of the former type.

The average capacity of electric refrigerators will increase. A popular size before the war was 3 cu. ft.; now, it is more generally accepted that a minimum capacity of 4 cu. ft. is preferable, and a "popular" model of that size is to be marketed by most manufacturers as soon as general production is resumed. To facilitate repairs, the units of all the principal manufacturers are in future to be standardised to the extent that they will be interchangeable, and, if a fault develops, another unit can quickly be fitted without removing the machine as a whole or waiting while one particular brand of unit is obtained.

Several companies have planned to introduce the built-in type of refrigerator, which will usually be mounted at table height for greater convenience in use. One of these is shown on the left of the kitchen in Fig. 229. There is a slight saving in production cost by this method, and, of course, for the rented home, there is an advantage in having such apparatus as a permanent fixture.

One interesting modification announced for future production is a "larder conditioner" (Fig. 235). It consists of a compact cooling unit which is fitted inside the larder and will maintain a temperature sufficient for normal food preservation; it does not, of course, incorporate any device for ice making. Larders in which these units are to be installed must have close-fitting doors and adequate heat insulation.



235. Prototype larder cooling unit.

Food Service

An important adjunct to the serving of food is the electric platewarmer, a simple heated stand on which dishes can be kept warm during the progress of meals.

HOME LAUNDRY

Motor-driven appliances are due to take an increasingly large part in easing the arduous work of home laundry.

Washing Machines

Before the war, electric washing machines were not so widely used in this country as they are in the U.S.A. The high prevailing prices partly accounted for this, but an equally strong deterrent was the British housewife's preference for boiling clothes. These difficulties are gradually being overcome as, on the one hand, machines at a more popular price become available and, on the other hand, women realise that the system of clothes agitation is a reliable alternative to boiling.

To bring these machines within easy reach of most homes, seven British manufacturers are producing a simple washer at a popular price. It will be square in cross-section, not exceeding 22½ in., and the capacity will be 10 gals. to the load line. Over the tub will be a detachable wringer which can be stored inside the cabinet when not in use, leaving a flat working surface to align with other kitchen units.

The machine, like the majority of makes, has a gyrator action. Other systems include (a) vacuum cup type of agitation, (b) a rotating and, reversing drum which revolves and tumbles the clothes inside, and (c) a high pressure water-injection process. In some of the more expensive

models, clothes can be rough-dried by centrifugal action in a separate tub or, in the case of the latest type, in the washing drum by the action of an automatic change-over switch.

Unless a separate wash-house is available, it is advisable to have space for the washer beside the kitchen sink (as in Fig. 230), so that the wringer can swing across the top of the sink and surplus water is drained away. The sink is also in a convenient position for rinsing. Some washing machines incorporate a pump, driven from the motor; by connecting a length of hose, water in the tub is automatically drained into the sink when washing has been completed.

Wash Boilers

As an alternative to the washing machine there is the electric wash-boiler, incorporating a 3 kw. heating element. On the better types, hand operated wringers are now being fitted, and in some cases a beating device is included, also hand operated.

Ironing and Drying

Supplementary apparatus for home laundry includes the electric iron (which, in future, will normally be fitted with thermostatic control), and the electric clothes dryer. Dryers are particularly applicable to flats where space for drying out of doors is restricted. The commonest form is a simple metal cupboard with racks, over which heated air circulates from the base by convection. A new design consists of a folding clothes horse enclosed in a fabric canopy; it has the advantage that it takes up only 1 sq. ft. of storage space when not in use.

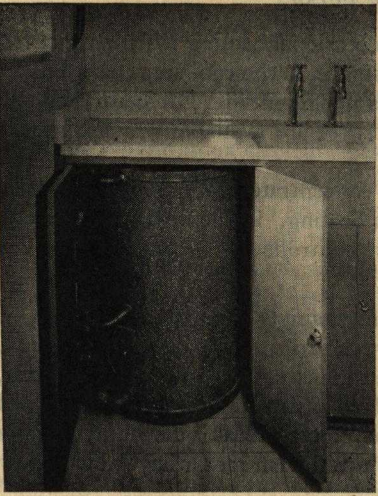
Where space for airing is limited, small cupboard heaters are available.

HOT WATER SERVICE

Electric water heating is itself of comparatively recent introduction and is following three systems. These are:

(a) *The Single Point Heater.*—This is a self-contained unit of the open-outlet non-pressure type designed for installation over the sink or bath. It has automatic heat control, substantial lagging, and capacity varies between 1½ gallons for washing up at the sink, to 20 gallons or more for the bath. Normally no extension to existing pipework is required, and installation is therefore simple and inexpensive. The system has been successfully applied in cases where large houses are converted into maisonettes; it has also been used where an additional hot water point is required at some distance from the central boiler, the alternative of a long hot-pipe run involving considerable heat losses.

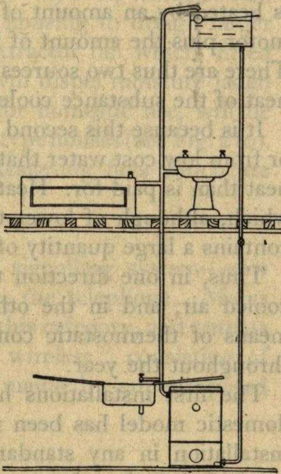
(b) *A Central Heater serving more than one outlet.*—This is a pressure-type, or cistern-type unit, lagged and thermostatically controlled. Its efficiency is largely dependent upon having a short pipe-run to the draw-



236. New dual-purpose water heater installed beside the kitchen sink.

off points. It is in this class that one of the most interesting new developments has arisen. Making use of the fact that hot water rises to the upper part of the boiler and does not readily mix with the incoming cold water at the bottom, the new heater has two elements at separate levels. The upper element, which is lightly loaded, is continuously connected and keeps 6 or 7 gallons of hot water always available for kitchen sink use. When larger supplies of hot water are required for a bath or for the week's washing, the lower heavily-loaded element can be switched on and the entire contents of the 20-gallon tank are heated. Fig. 236 shows one of these heaters installed beside the sink in a demonstration house at Northolt. The simplicity of the pipe-work can be seen in the diagram, Fig. 237.

(c) *Supplementary Heater used in conjunction with a Solid-Fuel Fire.*—This consists of a rod-type sheathed element immersed in the hot water tank and used for topping up the heat from the solid fuel boiler. By thermostatic control it assures that a reasonable supply of hot water is always available, and is additionally a service in the summer months when the boiler is not in use. This system has been adopted for use in the M.O.W. emergency factory-made houses. A 2 kw. immersion heater is fitted into the hot tank about 10-gallons from the top, and the upper section is lagged to reduce heat losses. Sufficient heat comes from the lower unlagged section of the tank to warm clothes in the airing cupboard in which the tank is fitted.



237. Installation of the dual purpose storage water heater.

SPACE HEATING

The main use of electric fires is for occasional heating when a room has to be warmed at short notice or, for instance, in the cool summer evenings when the sitting-room solid fuel fire is not required. For bedrooms and other rooms not in regular use, inset types are available which dispense with the need for a chimney.

Radiant fires with reflectors giving concentrated directional heat have been successfully applied for bathroom heating. In the interests of safety, these are fitted high on the wall and are controlled by a cord switch.

Convectors

Convection heaters are becoming increasingly popular on account of their safety (they are very suitable for nurseries) and ease of installation. Where the whole room is to be warmed quickly, the forced air convector, or " unit " heater is recommended. This consists of an electric heater coil working in conjunction with a motor-driven fan. Heat is distributed over a wide area. Earlier troubles with noise from the fan motor have now largely been overcome.

The Heat Pump

An interesting possibility for future development is the use of the mechanical refrigerating cycle in reverse as a heat pump.

The principle is best explained in relation to the ordinary domestic refrigerator. In the process of changing cold tap water into ice, the kitchen is heated by an amount of heat equal to the electric energy used by the motor plus the amount of heat taken from the tap water in the ice trays. There are thus two sources of heat, one paid for as kwh. and the other the heat of the substance cooled.

It is because this second quantity of heat can be taken from the free air or from low cost water that the system has the appearance of giving more heat than is paid for. Heat is simply extracted from an additional source which, although of lower temperature than the room being heated, still contains a large quantity of heat that can be made available.

Thus, in one direction the refrigerating cycle can be used to deliver cooled air, and in the other direction it will supply warmed air. By means of thermostatic control an even temperature can be maintained throughout the year.

The first installations have been applied to industry, and only one domestic model has been marketed (in the U.S.A.). It is designed for installation in any standard window, requires no water or drain connection, and plugs into an appliance outlet. It has sufficient capacity to heat a single room with an outdoor temperature of 40°F. Heating or cooling is selected simply by operating a 4-way valve. When used for cooling, this unit can cool at the rate of 6,000 B.Th.U./hour with an outdoor temperature of 95°F. and an indoor temperature of 80°F.

MISCELLANEOUS SERVICES

Timekeeping

The most important incidental benefit arising from the more general use of A.C. time-controlled supply in Great Britain is that it is making possible the use of synchronous electric clocks. The remaining areas served with D.C. are being changed over as quickly as possible, and it is reasonable to suppose that electric clocks will everywhere supersede the older systems. Apart from its dead-accurate timekeeping at negligible running cost, the synchronous clock is of such simple construction that it will operate for very long periods without repair. Also, being unaffected by damp situations, it can be fitted with safety even in bathrooms and steamy kitchens.

Ventilation

The ultimate aim is the fully air-conditioned home in which the air is not only maintained always at comfortable temperature, but is also constantly changed, filtered, and controlled for humidity. Apparatus for producing these conditions has been made commercially, but is not yet appropriate for common use owing to its comparatively high initial and running costs.

For the time being, we cannot expect mechanical ventilation in the home to go beyond the use of the familiar electric fan. This has been developed mainly in the form of the oscillating desk fan which gives a cooling effect to the skin in hot weather, or in the form of an extractor fan.

Although there will be a tendency in future housing to design larger kitchens, demand will still exist for a simple extractor fan which, fitted near the cooker or connected by a short duct, will dispel moisture laden air and cooking odours. Such fans, designed for domestic use, will be available and have been fitted in some of the prototype houses (see Fig. 230).

Good progress has recently been made in designing fans which are virtually noiseless.

Communications

Electric communications consist of the bell signalling system—now commonly fed from the mains—and, of course, the telephone. Mains radio and television should also be mentioned in this category, and patents have been taken out for a system of " wired wireless " consisting of transmission of programmes over the supply mains by superimposed frequencies.

Others

Among other electrical appliances for the home are electric firelighters, bedwarmers, sewing machines, refuse destructors (incinerators), and cigarette lighters.

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Page references in italics are to illustrations alone.